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Operation

BUSTER - JANGLE

NEVADA PROVING GROUNDS
OCTOBER-NOVEMBER 1951

Project 7.2 (Jangle)
Project 7.5 (Buster)

SEISMIC WAVES FROM A-BOMBS DETONATED OVER A LAND MASS

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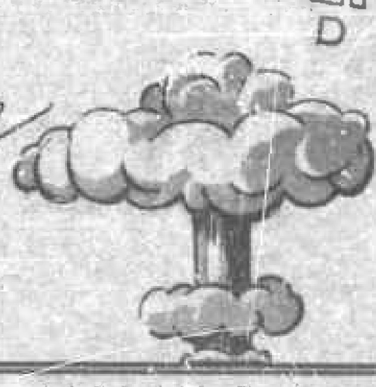

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PROJECT 7.2 (JANGLE)
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SEISMIC WAVES FROM A-BOMBS DETONATED OVER A LAND MASS

113

by

10 J. Allen Crocker

11 15 March 1952 12 119 p.

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ACKNOWLEDGMENT

It is desired to express, to the several agencies and the individuals directly concerned, appreciation for their contributions in this effort. The wholehearted and unreserved support afforded by all participants in this project resulted in an extremely smooth-running operation in the face of numerous obstacles and a yield of data which was far above all expectations.

ABSTRACT

Measurements were made of amplitude, wave type, frequency, propagation velocity and attenuation of elastic waves generated by A-bomb tests taking place in the center of a large land mass. This was accomplished by utilizing data from existing seismic observatories and supplementing these sources with data obtained from stations installed at strategic locations for the purpose of the test. Inferences are drawn about the capability of establishing scaling laws and of determining the energy in the blast by seismic measurements taken at long range. It is implied that additional effort will be expended in the analysis of records collected with the anticipation that such effort may produce criteria for distinguishing between natural and artificial seismic events. In addition, the advantages to long-range detection of the seismic and acoustic techniques working in concert are cited.

1.0 OBJECTIVE

The objective of this project was to gain a more complete understanding of seismic wave propagation emanating from atomic blasts in order that the routine operation of the seismic component of the Atomic Energy Detection System may be improved.

2.0 HISTORICAL AND THEORETICAL

The portion of the seismic spectrum which will permit the maximum signal-to-noise ratio for the recording of seismic energy from A-blasts has been postulated from a study of seismic records obtained from all scheduled A-bomb bursts, together with an intensive seismic research program. Seismic recordings of GREENHOUSE blasts indicated that there may be a signal which is characteristic of this type of event. It, therefore, becomes desirable to verify this observation, and even to accent the presence of such signals buried in background noise, by applying the same procedures of correlation which were worked out at the Naval Ordnance Laboratory Acoustics Division under AFOAT-1 Project Authorisation W/29. In addition, previous A-bomb blasts occurred at locations where there was no possibility of checking on theoretical assumptions that first motion from artificial seismic events would be compressions on all azimuths whereas first motions from tectonic events would be alternate compressions and rarefactions in the several quadrants. The combined programs of BUSTER and JANGLE offered an excellent opportunity for comparing at one location the effects of large blasts occurring in the air, on the surface and under the ground.

3.0 INSTRUMENTATION

Instrumentation employed in this experiment included accelerometers, displacement meters, tiltmeters and velocity seismographs. These were deployed with an assortment of 28 accelerometers, displacement meters and tiltmeters operated by the U. S. Coast and Geodetic Survey and producing 28 traces for close-in (less than 20 km) measurements; 74 displacement meters along a profile between Reno, Nevada and Prescott, Arizona operated by the 1009th Special Weapons Squadron personnel, supervised by the Naval Ordnance Laboratory, and producing 74 traces; and 26 velocity meters and one long-period displacement meter operated at long range (900 km to 2700 km) by Beers and Heroy and producing 39 traces, for a grand total of 129 instruments producing 141 traces.

Timing for close-in measurements was obtained over wire lines with signals originating at the control point and furnished by

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Edgerton, Germeshausen and Grier. Timing for the profile was obtained by radio communication between the control point and the several instrument locations. Timing at remote locations was obtained by conventional observatory practice. Correlation of the times at these several points was obtained by relating to world time as broadcast by WWV. Recording was done in some cases on photographic paper, in others on photographic film and in still other cases by utilizing pen and ink on paper recorders. Details will be covered in Appendices A, B and C. In addition, the Pasadena, Berkeley, and U. S. Coast and Geodetic Survey seismograph nets were alerted.

4.0 OPERATIONS

A field headquarters was established at Indian Springs Air Force Base which provided a secure analysis room, a radio net control known as AZTEC and a nerve center, with telephone communications over direct lines to the control point, to the Las Vegas long distance switchboard, and to the local telephone system. Radio communications were provided on 3052.5 and 6130 kc, together with a channel on the MARS network, with provisions for patching between radio and telephone circuits. Transmissions were made simultaneously on both 3052.5 and 6130 kc and were used for administrative, technical, logistic, and timing purposes. Time signals were broadcast, commencing with a verbal announcement at minus 30 minutes and comprised pulses at one-second intervals from minus 15 minutes to minus five minutes; a period of quiet from minus five minutes to minus 15 seconds; a steady tone from minus 15 seconds to minus five seconds; a period of quiet from minus five seconds to zero; a fiducial at zero and pulses at one-second intervals from plus two seconds to plus 30 minutes. Wired signals for close-in stations provided do pulses at minus 15 seconds, minus five seconds, zero and each second from zero to plus 30 minutes. At remote locations operations started at minus two hours and ran continuously to plus four hours. Seismograph observatories in the Pasadena, Berkeley, and U. S. Coast and Geodetic Survey nets had been requested to change their records at noon so that there would be no chance of losing a trace from this cause. Existing observatories were considered to be operational on 24-hour basis so no further communication was attempted with these units. Stations operated by Beers and Heroy were given a schedule of days and hours of proposed tests prior to the start of operations. Necessary changes in this schedule were communicated by telephone, referring to the written communication by paragraph and line. Instructions and changes in schedule were communicated to the U. S. Coast and Geodetic Survey for their close-in operation by personal contacts with the project officer. The profile extending from Reno, Nevada to Prescott, Arizona posed the greatest number of operational problems. These problems were solved by dividing this profile into seven sub-units, designated as Able through George,

respectively. Each sub-unit was placed under the leadership of an Air Force officer. These were, in turn, assisted by civilian personnel selected from the Naval Ordnance Laboratory because of their familiarity with the electronic equipment employed, and the entire effort was coordinated through an Air Force major serving in the capacity of technical liaison. Because of the time required to travel from the respective billeting areas to the operating sites (in some cases as much as 75 miles with large portions over paths where speeds were limited to five mph), together with the necessity to operate the equipment for five hours prior to shot time in order to assure stability of operation, it was necessary to commit the profile operators to an operation based on the forecast probability resulting from the meeting held at the control point at 2000 hours on D-1. A typical operation is as follows:

Immediately following the 2000 briefing at the control point, Lt. Col. Wignall called headquarters at Indian Springs to indicate the probability of meeting the test schedule. Upon receiving word that a morning test was probable, headquarters contacted each of the supervisors at their respective telephones giving them the forecast hour of the shot, the date, details pertaining to radio alerts and timing signals, and technical information so that each seismograph could be adjusted to the optimum setting corresponding to the prognosticated energy level. The supervisors relayed necessary information to individual field teams who in turn immediately moved into location. Upon arrival at the respective sites they started their power units, reported into AZTEC control by radio and prepared the technical equipment for the ensuing operation. This equipment was run for a long enough period to become stabilized and each team member had instructions that this stable condition must be achieved at least one hour prior to scheduled shot time. At minus 30 minutes AZTEC control sent out a coded message indicating that no more radio transmissions would be permitted except in extreme emergency conditions and the Atomic Energy Commission transmitters, 400 watts each, put their carriers on the air on both AZTEC frequencies. At minus 15 minutes the Atomic Energy Commission transmitters sent pulsed tones which were required to adjust signal levels into the timing mechanisms at each seismic station. These tone bursts persisted until minus five minutes, then there was just the carrier until minus 15 seconds. From minus 15 seconds to minus five seconds there was a solid 1000-cycle tone. This tone was terminated leaving only the carrier and was followed by a zero fiducial which was immediately followed by 1000-cycle tone bursts accurately spaced in one-second intervals which continued from zero until plus 30 minutes.

Each operator in the field had a table which indicated times at which he might expect seismic arrivals and air wave arrivals. All of these were expected to be over even at the most remote stations within

30 minutes of zero time. Upon completion of the test run the operator stamped his record tape, filling in prescribed data pertinent to the run, shut down his station, signed off by radio with AZTEC control and traveled by weapons carrier from his station to the nearest air field. His records were picked up by a B-25 aircraft which left Indian Springs on a pre-arranged schedule for the express purpose of rapidly collecting all data and of bringing supervisors to Indian Springs. Upon arrival of the courier aircraft at Indian Springs the supervisors worked up the individual data tapes for their respective stations and turned over these tapes to a group which reviewed, plotted and evaluated the results from the entire system. Following this evaluation there was a meeting of the supervisors wherein general problems were discussed and methods for correcting these were disseminated. Each supervisor was given a critique of the performance of stations in his unit, together with technical information which would improve his subsequent effort. On D plus 1 day the supervisors were returned to their base units by aircraft and the pertinent information acquired at headquarters was disseminated to the field teams for use in subsequent tests.

5.0 RESULTS

In order to appreciate fully the significance of the results obtained in operation BUSTER/JANGLE it must be realized that the arrays located at 8.2°, 9.3°, 9.6°, and 14.4° geocentric angle are in a belt (7° - 16°) defined as a close-in seismic shadow. Consequently, the establishment of detection within this belt permits one to extrapolate that detection would be accomplished under similar conditions at considerably greater distances on the far side of the seismic shadow where detection would be less difficult. In addition, it is necessary to understand that difficulties in processing contracts and other formal papers resulted in an inability to equip the array locations with the latest developments in instrumentation and consequently these arrays were not performing at a level consistent with proven technical capabilities. Nevertheless successful data were obtained as indicated in Table 1.1. Extrapolations from the profile records, where all shots have been normalized to Charlie burst and the ratio of maximum recorded amplitudes is plotted against ratio of energy size, indicates that the Surface and Underground shots are about equivalent to Baker. In addition, calculations based on measurements of seismic energy made at the source indicate that the Underground burst should be detected at 20° geocentric angle. These calculations and extrapolations are confirmed by the observations in Wyoming (1069 km) where, in fact, the recordings of the Surface, Underground and Baker shots were made.

TABLE 1.1

Summary of Seismic Energy Data from
BUSTER/JANGLE Shots

Shot	Signal to Noise	Instrument Gain	Maximum Range Recorded	
			km	Degrees Geocentric
Able		600,000	200	1.8
Baker	2:1	300,000	1069	9.6
Charlie	6:1	700,000	1069	9.6
Dog	6:1	600,000	1069	9.6
Easy			1069	9.6
Surface	1:1	400,000	911	8.2
Under-ground	2:1		1069	9.6

Participation in BUSTER/JANGLE permitted us to obtain data for:

1. Determining seismic attenuation constants for surface events

2. Placing brackets on capability of determining energy at the source from remote measurements

3. Increasing knowledge of source conditions and energy level which have a direct bearing on propagation by seismic means to long range

4. Assigning figures of merit to the contribution to be expected from a seismic station at a given location and

5. Investigating scaling laws.

In addition, we now know that:

1. The seismic energy of compressional waves from an A-bomb

blast is contained in the two octaves between 0.5 second and two seconds

2. The azimuthal effect is real and that first motion is compression for all locations, but this must be tempered because recording site conditions may cause an arrival to be so emergent that first motion cannot be determined unless three components are employed

3. There is no apparent change in period with shot size, within the range of sizes observed

4. There is a tendency toward one cycle per second waves for first arrivals regardless of shot size or zero location or whether the blast is in the air, on the surface or under the ground.

6.0 DISCUSSION

In a program as extensive as this where 141 seismograms were obtained for each of the several bursts it is not to be expected that detailed and complete analytical studies can be included in a report submitted so early subsequent to the conclusion of the field effort. Material has been selected to furnish a fair measure of the success of the operation from the standpoint of long distance recording. The inferences drawn have been stated and in general it is not anticipated that conclusions reached will be appreciably altered by further studies. In every case questionable data and doubtful conclusions have been omitted. It is interesting to note that for shots occurring at the same zero location (Baker, Charlie and Dog) records were very nearly similar to each other except for an increase in amplitude for successively larger bursts. The preliminary waves from Easy fall near the same pattern as those from earlier tests but the wave-to-wave semblance breaks down almost completely in the surface group due to a shift in the zero point by approximately one km. A log log plot of seismic amplitudes versus energy is included both in the U. S. Coast and Geodetic Survey and Naval Ordnance Laboratory reports. (See Appendices A and B.) It appears to be of significance that a straight line drawn through the points representing Baker, Charlie and Dog agree for both close-in and remote measurements and indicates a square law relationship. As a first approximation it may be concluded that a measurement of the amplitude of a trace is indicative of the energy in the blast.

7.0 CONCLUSIONS

In conclusion it is felt that the seismic surveillance component can make unique contributions in the following fields:

1. It provides a method of detection which is capable of working in concert with acoustic techniques for marginal situations resulting from high acoustic background or seasonal effects which prevent the placing of an epicenter by strictly acoustic means.

2. It offers a real possibility of placing brackets on the energy of the burst by seismic measurements made at remote distances.

3. It is still the only system which can detect true sub-surface events.

8.0 RECOMMENDATIONS

It is recommended that an attempt be made to solve some of the anomalies which appear to be associated with the shift in shot point and zero conditions. This can best be accomplished by a limited study of bursts at close range and a direct comparison between the double integration of accelerograph measurements and direct-reading displacement measurements. Such an undertaking is proposed in connection with Operation SNAPPER scheduled for May of 1952.

Fig. 1.1 Tent on Hillside

Fig. 1.2 Interior of Tent

Fig. 1.3 AZTEC Net Control

OPERATION BUSTER/JANGLE

PROJECT 7.2 (JANGLE)
PROJECT 7.5 (BUSTER)

REPORT OF FIELD ANALYSIS OF SEISMIC DATA

OBTAINED FROM OPERATION BUSTER/JANGLE

U. S. NAVAL ORDNANCE LABORATORY

PARTICIPATION

by

M. M. Coate
H. N. Opland
J. Pomerantz

24 January 1952

APPENDIX A

ACKNOWLEDGMENT

The authors wish to take this opportunity to commend the airmen and officers of the 1009th Special Weapons Squadron for their outstanding performance in recording the data at the profile stations. The high-caliber work of these operators and supervisors in processing and analyzing the data in the field under adverse conditions and with limited time schedules indicated a profound interest in the project and a good understanding of the procedures and objectives involved. It is doubtful if more competent operators and supervisors could have been found even among scientific personnel with specific backgrounds in seismology.

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1. "The Basin and Range Province in Utah, Nevada, and California," by Thomas B. Nolan, USGS Prof. Paper 197-D, 1943. (Unclassified)

2. "Seismic Refraction Survey For Navy Contract NOy-26616, Nye County, Nev.," by United Geophysical Co., Inc., July 27, 1951. (Unclassified)

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ABSTRACT

This report covers the preliminary and field analysis of profile seismic data from six atomic events: Four airbursts, one surface shot, and one underground shot. These data were recorded between 20 and 450 km from the shot point, ranging from Reno, Nevada to Prescott, Arizona. Differences and similarities in seismic signals are noted, travel-time curves for first arrivals were plotted, and structure of the crust in a portion of the southwest United States is inferred. Periodic content, distribution of maximum recorded amplitudes with distance, and variations of maximum recorded amplitudes with shot size are plotted and briefly discussed. Methods of field analysis are described and suggestions made for future analysis of these data. The data, in most cases, will allow refinements if sufficient time is available for further analysis.

A.1.0 AUTHORIZATION

This analysis was authorized by Headquarters, USAF, Office for Atomic Energy, DCS/O, AFOAT-1 through the Office of Naval Research and was performed under Task Number NOL-198-52. Additional work such as site selection, instruction to Air Force personnel in instrument operation, and field consultation was also performed by Acoustics Research Division personnel and an operational summary report of these activities will be forthcoming at a later date.

A.2.0 INSTRUMENTATION

The data that were analyzed for this report were taken at the profile stations during the BUSTER/JANGLE Operation using Naval Ordnance Laboratory LF Type 6A Seismographs. Figure A.1 shows the approximate locations of the stations in the profile. The letters N, S, E and W refer to the approximate direction of the stations from ground zero at the Nevada Test Site and the number refers to the approximate distance from the test area in tens of kilometers. Three-component stations were established at N-20, E-20, S-20, S-15, S-14, S-13, S-12, S-11, W-11, N-11, E-11; and two-component stations were established at S-2, S-3, S-4, S-5, S-6, S-7, S-8, S-9 and S-10. All the remaining stations contained a single vertical seismograph. The two-component stations contained two horizontal seismographs, oriented so that one recorded transverse (Y) motion and the other longitudinal (X) motion, relative to the direction from ground zero. The three-component stations contained two horizontal instruments, oriented as above, and one vertical seismograph. In addition, extra vertical instruments were installed at S-6, S-9 and S-10 for JANGLE shots and the transverse instrument at S-2 was replaced with a vertical for these shots. Records were taken using Esterline-Angus recorders run at a tape speed of approximately 12 inches per minute. The timing marks recorded were supplied by radio from the Nevada Test Site and/or by deck clocks and chronometers which were periodically calibrated with WWV timing. A fiducial, or shot instant, pulse was broadcast for most of the events by the Test Site Radio and was recorded to varying degrees of satisfaction. Instrument parameters (period, damping, calibration deflection, and sensitivity setting) were recorded before and after each "signal" run. Before the seismographs were taken into the field they were calibrated on shaking tables at the Naval Ordnance Laboratory and their individual calibration constants (F) were determined.

A.3.0 OPERATIONAL ANALYSIS OF DATA

The station operators, assisted by their supervisors, performed the initial analysis of their records before forwarding them to a

central field office. This consisted of noting on the records in the blanks of a stamp provided for the purpose, the following:

(a) Station, component and date
(b) Time of calibrations, calibration sensitivities and calibration deflections in scale divisions
(c) Damping, period and run sensitivity
(d) Chronometer error (at time of shot) and first arrival time (time in seconds from fiducial to first arrival)
(e) True time of first arrival, true time of maximum arrival
(f) Duration of signal, dominant period of signal
(g) A calculation incorporating some of the above information to arrive at a value for the maximum amplitude in microns (10^{-4} cm)

This analysis from all stations was spot-checked and compiled in the field office and rough estimates of travel-times, amplitudes, periodic content and trace characteristics were obtained to enable the project officer of the contracting agency to make post-shot reports. The information contained in the remainder of this report supersedes any information given to the project officer for use in the post-shot reports.

A.4.0 GEOLOGIC CONSIDERATIONS

To facilitate brevity in this report only general statements of the surface geology will be given here. The depositional and tectonic history of the region covered by the profile was such that the surface layers underlying stations N-6 through N-15 are different in lithology and structure from the surface layers underlying stations S-2 through S-15, reference (1). Geologic foundations at the individual stations may be expected to affect the recording of seismic energy, and the majority of the stations were therefore located on competent formations ranging from coarse-grained granites through rhyolites to dense limestones and metamorphics. The stations which can be considered as being located on semi-consolidated formations are S-15, N-7, N-14, N-15, N-20, N-25 and E-11. Stations which were located on unconsolidated formations were S-20, S-10 and S-8. The semi-consolidated sites consisted of loosely cemented sandstones, small fractured limestone outcrops surrounded by large areas of alluvium, breccias and fractured metamorphics. The unconsolidated sites consisted of alluvium valley gravels or small outliers of incompetent formations in valley alluvium. It is expected that the major effect of the geologic characteristics of a site on the recorded seismic signals will be evidenced in the seismic displacement with perhaps a minor effect in the periodic content of the records. It has been observed by many seismologists

TABLE A.1

Apparent First Arrivals For Shots
(Seconds After Detonation)

Station and Component	Baker	Charlie	Dog	Easy	Under-Ground
N 7.2 A *	-	2.74	2.92	2.56	-
N-2 *	-	5.82	5.10 d	4.83	-
N-2 z	-	4.9 d	5.10 d	4.8 d	-
N-6 z	-	12.25 d	12.4 d	12.0 ?	11.6 d
N-7 z	-	14.05 d	14.3 d	14.1 d	13.4 d
N-8 z	15.0	-	15.1 d	18.6?d	14.1 d
N-9 z	17.2	17.1 d	17.3 d	17.0 d	16.1 d
N-10 z	18.9	18.8 d	19.1 d	18.9 d	17.4 d
N-11 z	-	20.3 d	20.4 d	20.2 d	18.8 d?
N-11 x	22.3 ?	20.4 u	20.4	19.8 u	-
N-11 y	-	22.3 d	-	22.1	-
N-12 z	22.3	22.0 d	22.2 d	21.8 d	20.4 d
N-13 z	-	23.6 d	23.7 d	23.4 d	22.2 d
N-14 z	26.3	25.8 d	25.9 d	25.7 d	24.2 d
N-15 z	26.9 ?	27.2 d	27.2 d	27.0 d	25.9 d
N-20 z	33.6 ?	33.4 d	33.4 d	33.4 d	33.5 d
N-20 x	-	-	-	33.35 u	33.5 u
N-20 y	-	-	-	-	-
N-25 z	38.9 ?	-	38.9	37.9 d	37.6 d
N-30 z	-	46.0	45.7	45.8 d	51.4 d?
N-35 z	-	-	51.4 ?	57.5 ?	50.5 ?
N-40 z	-	-	59.5 d?	-	-
N-45 z	-	65.8	65.9	-	-
S 7.2 A *	-	2.20	2.30	2.0 ?	-
S-2 *	-	3.45	3.6 ?	3.61	-
S-2 x	3.7	3.45 u	3.5 u	3.55 u	-
S-2 y	3.8	-	3.55 d	3.6 d	-
S-3 x	-	5.0 u	5.0	5.2 u	6.2 u
S-3 y	-	-	5.0	5.4 u	

* Coast and Geodetic Survey Station

TABLE A.1 (Continued)

Apparent First Arrivals For Shots
(Seconds After Detonation)

Station and Component	Baker	Charlie	Dog	Easy	Under-Ground
S-4 x	-	7.0 u	7.1 u	7.2 u	7.9 u
S-4 y	-	-	-	7.8 ?	-
S-5 x	8.45 ?	8.3 u	8.4 u	8.3 u	9.4 u
S-5 y	-	-	-	8.9 ?	-
S-6 x	-	10.2 u	10.3 u	10.2 u	11.3 u
S-6 y	-	10.6 d	10.8 d	10.2	11.1 d
S-6 z	-	-	-	-	11.1 d
S-7 x	-	11.9 u	12.0 u	12.0 u	12.9 u
S-7 y	-	12.4 u	12.0 d	12.5	13.2 u
S-8 x	-	13.7 u	13.8 u	13.7 u	14.9 u
S-8 y	-	13.8 u	-	-	15.0 u
S-9 x	-	15.2 u	15.2 u	15.4 u	16.1
S-9 y	-	15.1	15.3 u	15.0	-
S-10 x	17.5 d	16.5 u		16.7 u	18.9 u
S-10 y	17.4 d	16.7 d	17.5 ? d	-	18.9 u
S-10 z	-	-	-	-	18.4 d
S-11 x	18.1	17.4 u	17.6 u	17.5 u	19.7 u
S-11 y	18.9 d	17.8 u	18.1 u	17.7	-
S-11 z	18.9 d	17.4 d	17.6 u	17.5 d	20.0
S-12 x	-	-	19.9 u	20.0 u	22.0 ? u
S-12 y	-	-	-	20.7 u	-
S-12 z	-	-	20.0 d	20.4 u	20.1 d
S-13 x	22.3 d	22.2 d	22.3 d	21.6 u	23.4 u
S-13 y	-	22.2	-	-	-
S-13 z	22.2 u	22.1 u	22.2 u	22.4 u	23.2 u
S-14 x	23.2 u	23.0 u	23.1 u	23.1 u	24.4 d
S-14 y	24.9 u	24.2 d	24.3 d	23.7 u	24.8 d
S-14 z	23.7 u	23.7 u	23.6 u	23.7 u	25.0 d
S-15 x	25.8 d	25.7 d	26.1 u	25.2 u	26.5 d
S-15 y	-	25.8 d	25.8 d	25.8 d	-

TABLE A.1 (Continued)

Apparent First Arrivals For Shots
(Seconds After Detonation)

Station and Component	Baker	Charlie	Dog	Easy	Under-Ground
S-15 z	25.7 u	25.2 d	25.3 ?	25.2 d	26.5 u
S-20 x	33.6 u	-	-	-	-
S-20 y	-	-	-	33.6	-
S-20 z	-	31.0 u	-	31.1 u	31.8 u
S-25 z	38.9	-	38.3 d	38.3 d	38.9 ?
S-30 z	-	45.3	44.8 d ?	44.7 d	-
S-35 z	-	51.9 u	52.1	51.6	-
S-40 z	-	57.6 ?	57.7 ?	55.7 u ?	-
S-45 z	-	-	63.9 ?	-	-
E-11 x	-	23.0 u ?	-	21.7 u	22.0 u
E-11 y	-	-	-	23.0 d ?	-
E-11 z	-	-	21.85 d	21.6 d	21.1 d ?
E-20 x	-	-	33.0 u	-	33.3 ?
E-20 y	-	-	35.4 u	-	-
E-20 z	-	-	33.1 d	32.9 d	33.6
W-11 x	-	19.5 u	19.6 u	19.5 u	20.4 d
W-11 y	-	-	-	-	-
W-11 z	-	19.5 d	19.6 d	19.5 d	20.5 d
West B *	-	3.64	3.83	3.49	-

* Coast and Geodetic Survey Station

can be extended to 450 km with many strong, unmistakable second arrivals. The equation of the travel-time curve for Charlie and Dog combined is

$$t = 1.5 + \frac{X}{6.06} \qquad (A.1)$$

where t is the time in seconds and
X is the epicentral distance in kilometers.

This equation was derived by graphical means, rather than by a least square solution. An interesting thing about the second arrivals comprising the line defined by equation A.1 is that they appear as compressions at the North stations, and rarefactions at the South stations.

At about 24 to 25 km, a strange anomaly occurs, the arrivals at stations N-2 and S-3 occur 0.4 to 0.6 second earlier than the expected times from the above travel-time line. No explanation for this is presently available. Another anomaly is a line running parallel to the above-mentioned first arrival line, but arriving 0.4 second earlier. This early line extends from S-11 to S-15. The surface geology in this area exhibits a high degree of complex folding and faulting and the simplest explanation of the early arrivals is to postulate a block uplift of the higher velocity basement rocks associated with or causing this surficial complexity.

The travel-time line given by equation A.1 intersects what is approximately an 8 km/sec-velocity first-arrival travel-time line at about 155 km. Arrivals which fall on the 8 km/sec-line were found to extend back (as second arrivals) at least to N-7 (about 76 km) and may perhaps be present even closer to the shot point. These second arrivals are very striking on the North stations. The second arrivals on the seismograms can be seen getting closer and closer to the first onset until at N-15 it comes in with great strength as a first arrival. The equation of this second line is

$$t = 7.6 + \frac{X}{7.97} . \qquad (A.2)$$

The equation of the line determined from the obvious later arrivals, primarily those read on the transverse component tapes, is

$$t = 1.5 + \frac{X}{3.4} . \qquad (A.3)$$

This line represents the refracted transverse (S) wave corresponding to the refracted longitudinal (P) wave given by equation A.1.

A preliminary analysis based on equations A.1 and A.2 and the data in reference (2) places the refracting depth associated with the

6 km/sec-velocity at approximately a depth of two kilometers, and the depth associated with the 8 km/sec-velocity line at about 30 km. The analysis assumed that for shot Dog the effective impact arrived at the earth 0.5 second after the shot time. This assumption was based on the data given in reference (3).

The time-distance chart for the Underground shot indicated that between 31 and 150 km the line of first arrivals is given by

$$t = 0.9 + \frac{X}{5.96} . \qquad (A.4)$$

This equation shows the approximate correctness of the last assumption in the above paragraph. Arrivals at stations N-10, N-11, and N-12 appear to be about 0.3 second early. Attention is called to the fact that the first arrivals for S-12 to S-14 are completely missing at these stations. The apparent first arrivals at these stations seem to be that of the P_n waves.

There were only a few first arrivals to determine the 8 km/sec-velocity line (P_n). However these were combined with the later arrivals to determine the line

$$t = 7.1 + \frac{X}{8.0} . \qquad (A.5)$$

The difference in intercept time between equations A.5 and A.2 is seen to be 0.5 second. A line roughly paralleling that defined by equation A.5 and comprised solely of South station arrivals is also suggested by the travel-time chart for the Underground shot. Its equation is

$$t = 8.1 + \frac{X}{8.2} . \qquad (A.6)$$

This line, if real, may be associated with the transformed refracted wave.

The plot of the obvious later arrivals for the Underground shot shows considerable scatter, whose significance cannot be discussed here. The line through the most and earliest of these arrivals was found to be defined by

$$t = 2.1 + \frac{X}{3.45} . \qquad (A.7)$$

This line corresponds, of course, to the S wave previously defined by equation A.3.

First arrivals were examined to determine whether compression is the first motion on all azimuths from an explosion, as contrasted with alternate compressions and rarefactions for first motions relating to tectonic events. The direction of first deflection at various stations for several shots is given in Table A.1 beside the time of first arrival whenever this was read. In this table, "u" refers to an upward motion, "d" to a downward motion on the record with time increasing to the analyst's right. For a vertical instrument a downward motion (d) corresponds to a compression and for a horizontal instrument an upward motion (u) corresponds to a compression. It will be noted that for the great majority of the stations and events the seismograms exhibited compression as the first motion on both the longitudinal (X) and the vertical (Z) components. (The transverse component is disregarded in this discussion because first arrivals on the transverse components were small and often illegible, and first motion either up or down would only be an indication of how close the instrument was oriented with regard to a true bearing to the shot point.) However, an interesting phenomenon occurs in the region between S-11 and S-15. Some of the records taken at these stations exhibit an apparent rarefaction as the first motion.

An examination of the Charlie, Dog and Easy records showed that at S-11, compressions arrived simultaneously as first arrivals and were registered for both X and Z components. At S-12, a compression was recorded on X, a rarefaction on Z; the X arrival coming in earlier. At S-13, simultaneous rarefactions were registered as apparent first arrivals on both the X and Z components for shots Baker, Charlie and Dog, and on the Z component for shot Easy. However, a compression was exhibited as first motion on the X component for Easy, the largest shot, and the arrival time was earlier than that on the Z component. At S-14, the X component consistently led the Z component in time, and arrived as a compression; the Z component appeared as a rarefaction. At S-15, the first motions on the X and Z components were compressions for shot Easy; the first motion on Z component was compressional and arrived ahead of the motion on X component for shots Charlie and Dog, the X component arrived appearing as a rarefaction.

The above leads to the following conclusion:

Whenever a seismic arrival from an explosion is of sufficient amplitude to appear as the true first arrival, the first motion is a compression. However the first half cycle of the wave may be too weak either on the X or Z component to appear at all, and then the first motion appears as a rarefaction. Thus it is not a safe procedure to say that a record was not that of an explosion because the first motion was a rarefaction. It is, moreover, of advantage to have three-component instrumentation since the true first arrival may show up stronger either on the longitudinal or the vertical component.

Furthermore it may happen, as it did for S-11 to S-14 for the Underground shot, that many cycles of the signal are not recorded. Perhaps there are certain geological formations more prone to exhibit weak first arrivals than others. This should be investigated, and such formations should be avoided.

For the Underground shot, later arrivals at approximately six and eight minutes were recorded at about 15 stations. The periods were approximately one second and these arrivals are probably reflections from the earth's core or a shallower reflecting horizon.

A.6.0 PERIODS

Seismic records for Baker, Charlie and Dog shots were "overlays" in the sense that they correlate cycle for cycle but are not necessarily overlays in regard to amplitudes. For Easy shot discrete portions of the records, especially in the early portions, were easily correlatable and hence exhibited the same periods as did records from the previous shots. In the above respects, for Operation BUSTER, periods did not change from shot to shot at any one station for similar shot points regardless of size of shot. Periods associated with first arrivals recorded at all stations were between 0.7 and 1.1 seconds. Periods of later arrivals varied from one to two seconds.

Seismic records from the surface shot exhibited shorter periods more or less superimposed on periods similar to those associated with the BUSTER records. These superimposed periods ranged from 0.25 to one second and occurred mostly in the early parts of the records. Records obtained from the underground shot were quite different in periodic content from the BUSTER air bursts and the JANGLE surface records. Here the shorter periods occurred throughout the records both as superimposed and as dominant periods. These periods again ranged from 0.25 to one second. The first few cycles of most of the seismograms from all the events seem to exhibit a tendency toward a one-second period, even with the superposition of the shorter periods recorded the JANGLE shots. In connection with the analysis of Charlie and Underground records for the statistic E_1 (explained in Section A.8.0) a large sampling of "average dominant" periods was obtained. An average of these values gave an "overall average" of 1.10 for Charlie (187 samples) and 0.74 seconds for Underground (173 samples).

A.7.0 AMPLITUDES

The amplitudes discussed in this section are the maximum trace amplitude appearing at each station, for each shot, without regard to

time or waveform correlation with any other station. They are measured from peak-to-peak and converted into micron displacements. The measurements and conversion were done in the field and the following analysis is based primarily on the field work.

To obtain more dependable figures certain corrections should be applied. The measurement of calibration parameter and signal displacements should be checked and refined. A correction for frequency response should also be made. As this is an extremely time-consuming process such checking did not appear profitable.

In some cases the trace ran off-scale, the pen failed to write, or some other fault occurred in the recording. In such cases maximum amplitudes have been estimated wherever possible.

The amplitudes, as described above, for all stations and all shots except Able, are listed in Tables A.2, A.3 and A.4. Table A.5 gives the best available distance of each station from the zero point of each shot (except Able). Figure A.2 shows plots of amplitude versus distance for the North line, Z-components, for all shots except Able and Baker.

The relation of amplitudes from shot to shot at any given station is a function of several things. Important among these are shot size and shot position. In order to investigate the relation of shot size to amplitude received, it is necessary for the shot position to remain constant or to make correction for the effects of change in shot position.

For the present assume that shot position remained fixed for all shots. Then the ratios of the recorded amplitude for one shot to that of another shot at a given station should be the same for all stations. Figure A.2 shows that this is approximately true in our case. By computing the ratio at all stations and taking an average, small errors occurring at individual stations should be minimized. The North and South lines are treated separately because our assumption is not quite true. If we take Charlie shot as unity we have the ratios indicated in Table A.6.

In connection with these ratios the following things should be noted. First, many of the amplitudes for the Underground shot are estimates. Second, on the North line there are only two stations having horizontal components and so the increase of the ratios exhibited by the X components for the JANGLE shots may not be significant. And third, while the final averages of the ratio for the horizontals on the South line do not differ too much from the averages for the verticals, there was much more variation among the individual horizontal stations.

TABLE A.2

Summary of Maximum Amplitude in Microns of Z Component

Station	NORTH					
	Baker	Charlie	Dog	Easy	Surface	Under-ground
2	4.47	12.7	14.8	31.9	6.75	8.07
3,4,5	-	-	-	-	-	-
6	1.23	3.65	8.0*	5.64	1.24	1.60
7	2.88*	6.84	7.39	12.5*	1.42	1.38
8	0.471	1.47	1.73	2.33	0.497	0.435
9	1.12	2.81	3.5	5.55	1.005	0.977
10	0.57	1.87	2.03	3.3*	0.692	0.885
11	-	0.818	1.08	1.725*	0.421	0.465
12	0.225	0.758	0.935	1.60	0.194	0.292
13	0.297	0.756	0.875	1.73	0.304	0.311
14	0.495	1.579	1.77	2.49	0.408	0.612
15	0.345	1.001	1.31	1.73*	0.262	0.234
20	0.345	1.145	1.24	1.73*	0.304	0.253
25	0.25	0.80	0.91	1.5*	-	0.160
30	0.09	0.291	0.327	0.468*	-	0.062
35	0.046	0.13	0.155	0.26*	0.051	0.068
40	0.042	0.11	-	-	0.038	0.04
45	0.0298	0.08	0.088	0.036	0.051	-

*Estimated

TABLE A.2 (Continued)

Summary of Maximum Amplitude in Microns of Z Component

Station	SOUTH					
	Baker	Charlie	Dog	Easy	Surface	Under-ground
2	-	-	-	-	28.4	22.04
3,4,5	-	-	-	-	-	-
6	-	-	-	-	0.386	-
7,8	-	-	-	-	-	-
9	-	-	-	-	0.654	0.83*
10	-	-	-	-	1.407	2.13
11	0.334	1.21	1.35	2.54	0.359	0.80*
12	0.206	-	1.11	1.60	0.249	0.35*
13	0.422	1.32	1.56	1.75	0.311	0.39*
14	0.350	0.87	1.05	1.18	0.423	0.488
15	0.436	1.35	1.50	2.55	0.275	0.385
20	0.616	1.94	2.02	2.33	0.334	0.46*
25	0.068	-	0.288	0.319	0.049	0.065*
30	0.146	0.487	0.478	0.519	0.068	0.09*
35	0.026	0.067	0.077	0.162	0.018	0.008*
40	0.056	0.167	0.175	0.157	0.030	0.043
45	0.041	0.061	0.178	0.218	0.026	0.042*

*Estimated

TABLE A.3

Summary of Maximum Amplitude in Microns

Station	SOUTH - X Component					
	Baker	Charlie	Dog	Easy	Surface	Under-ground
2	>24.0	38.0	-	34.3	39.35	38.2
3	9.77	24.5	13.4	14.9	4.35	5.712
4	3.99	9.17	7.1	-	2.74	-
5	2.01	9.98	11.5	14.12	1.69	2.162
6	1.91	5.52	5.77	10.96	0.804	1.71
7	0.97	2.31	2.89	-	0.695	-
8	0.44	4.32	4.46	6.14	0.734	1.181*
9	-	1.95	2.88	4.32	1.16	1.59
10	2.77	7.51	-	14.0	2.03	2.29
11	0.292	1.87	2.05	2.42	0.384	0.830*
12	0.313	-	1.15	2.19	0.3815	0.62*
13	0.495	1.52	1.67	3.13	0.401	0.95*
14	0.457	1.32	1.50	2.35	0.445	0.577
15	1.020	3.80	1.38	5.79	0.771	1.38*
20	1.69	2.25	5.36	4.05	0.523	0.65*

*Estimated

TABLE A.3 (Continued)

Summary of Maximum Amplitude in Microns

Station	SOUTH - Y Component					
	Baker	Charlie	Dog	Easy	Surface	Under-ground
2	>24.0	42.3	-	96.0	-	-
3	7.41	19.65	10.7	19.6	4.18	6.82
4	1.90	2.78	7.52	10.1	1.77	2.28
5	3.91	9.68	10.1	-	1.81	1.35
6	1.45	6.28	7.32	10.01	0.759	-
7	1.17	5.80	7.34	11.8	1.069	-
8	1.02	-	2.86	7.63	0.905	-
9	-	2.07	3.58	3.27	0.49	0.924*
10	2.27	5.81	6.35	12.5	1.477	1.95
11	0.334	1.43	1.33	1.84	0.407	0.964*
12	0.278	-	1.05	1.98	0.53*	1.07*
13	0.665	1.61	1.83	2.64	0.553	1.12
14	0.350	1.03	1.38	2.21	0.446	0.910*
15	0.905	1.90	1.79	2.57	0.446	0.633*
20	1.39	3.74	2.34	7.47	0.997	1.11

*Estimated

TABLE A.4

Summary of Maximum Amplitude in Microns

Station	Baker	Charlie	Dog	Easy	Surface	Under-ground
	X Component					
N-11	0.504	1.45	1.69	3.02*	1.56	1.47
E-11	1.8	3.87	5.04	6.95	1.78	2.23
W-11	0.398	1.05	1.36	1.50	0.45	1.10
N-20	0.399	0.938	1.13	1.53	0.404	0.484
E-20	-	0.856	1.05	2.72*	-	0.384
	Y Component					
N-11	1.02	3.14	3.12	5.14*	1.21	2.31
E-11	2.17	4.56	5.03	7.87	2.20	3.20
W-11	0.610	0.879	1.72	2.17	0.788	0.936
N-20	0.684	1.517	1.78	3.37*	0.538	0.444
E-20	-	1.36	1.60	1.72	-	0.496
	Z Component					
W-11	0.104	1.47	1.88	2.28	0.612	1.00
E-11	2.00	4.98	6.98	8.40	2.00	2.88
E-20	0.493	1.08	1.23	1.72*	-	0.350

*Estimated

TABLE A.5

Distances in Kilometers from Shot Point to Station

Station	Baker, Charlie Dog	Easy	Surface	Under-ground
N-2	25.0	24.18	19.7	17.37
N-6	66.2	65.8	64.3	63.7
N-7	76.1	75.7	73.8	73.1
N-8	82.1	81.5	78.8	78.3
N-9	95.0	94.6	91.8	90.6
N-10	105.3	104.6	101.7	100.3
N-11	115.1	114.3	110.7	108.9
N-12	125.0	124.3	120.8	119.0
N-13	134.3	133.5	129.8	127.9
N-14	146.6	145.8	141.7	139.6
N-15	156.2	155.4	151.4	149.4
N-20	206.9	206.2	202.6	200.8
N-25	250.6	249.8	245.9	243.9
N-30	305.8	305.0	301.3	299.4
N-35	355.0	354.2	350.4	348.4
N-40	405.2	404.4	400.4	398.3
N-45	454.1	454.8	450.8	448.8
S-2	13.4	14.3	18.88	21.36
S-3	24.2	25.05	29.55	31.90
S-4	34.2	35.1	39.6	42.0

TABLE A.5 (Continued)

Distances in Kilometers from Shot Point to Station

Station	Baker, Charlie Dog	Easy	Surface	Under-ground
S-5	42.7	43.5	48.1	50.5
S-6	53.4	54.3	58.8	61.2
S-7	63.7	64.6	69.0	71.4
S-8	73.6	74.4	78.8	81.4
S-9	82.5	83.4	87.5	89.6
S-10	89.3	90.1	94.3	96.6
S-11	98.8	99.6	103.7	105.8
S-12	114.0	114.9	118.8	120.9
S-13	124.2	125.0	128.9	130.9
S-14	133.4	134.2	138.1	140.1
S-15	145.4	146.3	150.1	152.1
S-20	188.5	189.4	193.3	195.3
S-25	237.4	238.3	242.2	244.3
S-30	295.6	296.4	300.4	302.5
S-35	347.6	[illegible]8.4	352.1	354.0
S-40	395.3	396.2	400.1	402.1
S-45	444.7	445.6	446.4	448.5
W-11	113.9	111.8	112.9	113.7
N-11	127.2	126.8	124.8	123.6
N-20	204.8	204.3	199.8	197.8

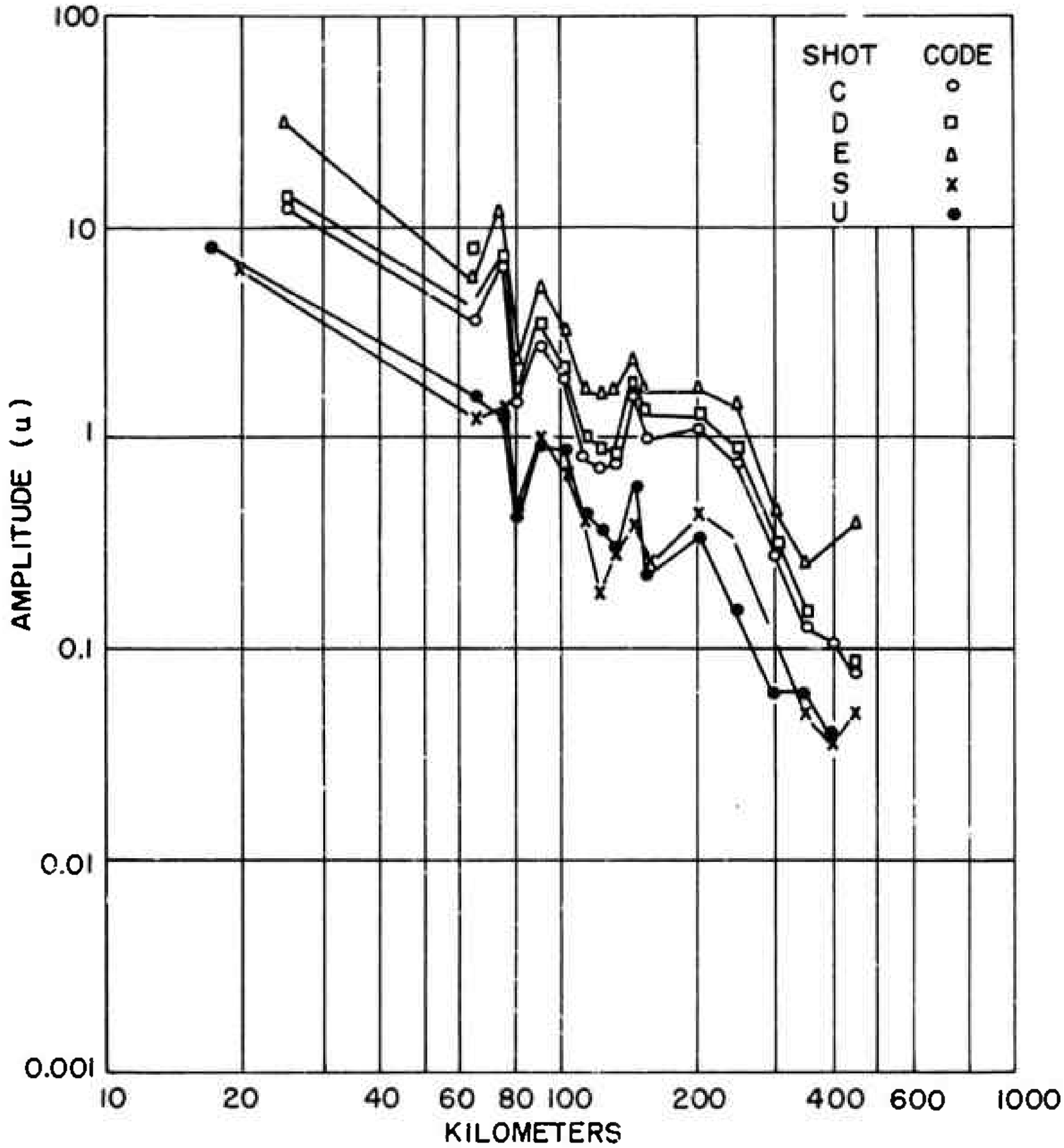


Fig. A.2 - Preliminary Plot of Amplitude vs Distance
North Line - Vertical Components

TABLE A.6

Amplitudes Normalized to Charlie

	NORTH LINE COMPONENTS Z	X	Y	SOUTH LINE COMPONENTS Z	X	Y
Baker	0.345	0.386	0.380	0.333	0.345	0.375
Dog	1.17	1.18	1.06	1.10	1.11	1.01
Easy	1.99	1.86	1.87	1.54	1.63	1.68
Surface	0.365	0.76	0.363	0.248	0.260	0.283
Under-ground	0.368	0.762	0.507	0.325	0.392	0.497

The ratios for shots Easy, Surface and Underground are lower for the South line than for the North. This may be due to the fact that in reality the shot position did change. If the zero point is moved the amplitudes may be affected by the change in distance and travel path to the station and by the change of site characteristics of the zero area itself. If the height of the burst above the zero point is changed the amplitudes will be affected by the change in impact at the zero point, or if the height is decreased below a certain point, by a change in the manner the energy is transmitted to the earth. When the burst is high and the per cent change of height not too large, the change in height may be lumped with the size of shot because the manner in which the energy is transmitted to the ground has not changed. In the case of shots Baker, Charlie and Dog the only change in position was in the height of burst. This was not large and hence, if a correction were applied to the size of the shots, they could be considered as all occurring at the same altitude. That this assumption is justified is borne out by the already mentioned remarkable similarity of the records (Section A.6.0).

The arguments presented above allow us to apply the appropriate ratio from Section A.7.0 to the amplitudes, given in Tables A.2 and A.3, for Baker and Dog shots. This will convert these data to approximately that which would have been obtained if shots of Charlie size and position had been fired in place of Baker and Dog. Call this computed

data Baker' and Dog'. Now if the data from an individual station for Baker', Charlie and Dog' is averaged, the small errors peculiar to an individual shot will be minimized. The data resulting from this averaging process will be used to study the relation of amplitudes from station to station. Table A.7 lists these "average Charlie" amplitudes, and Figure A.3 shows a plot of these amplitudes versus distance. The straight line in Figure A.3 represents a square law decrease of amplitude with distance.

The amplitude of a given station for any one shot will be a function of the following parameters:

(1) Local site characteristics
(2) Local instrumentation
(3) Distance from the source

Although some information has been gained by preliminary studies, the separation of these three effects, and possible definition of others, presents an interesting problem for future investigations. Local site characteristics have been discussed in Section A.4.0 and as was predicted sites on semi-consolidated and unconsolidated formations, such as N-7, N-9, S-10 and S-20 show tendencies to be high.

It appears that in this operation, local instrumentation had no major effect on the amplitude variation. For instance, if an instrument was incorrectly calibrated, i.e., the wrong F given, this would cause the calculated amplitude to be too high or too low. It is improbable that at the three-component stations all instruments would have an error in calibration in the same direction. But Figure A.3 shows that all components at the three-component stations tend to read high or low together. Again if there were a gross error in the F's the amplitudes would tend to be high or low with the F's. A comparison of the F's with amplitudes shows no correlation. Thus it seems that large variations can not be explained by local instrumentation.

Two effects of distance on amplitude seem to show up immediately from Figure A.3. First, there is a general decrease of amplitude with distance following some law approximating the square law. Second, there is a hump in this curve at about 150 km that cannot be attributed to local site characteristics. This occurred on both the North and South lines. An explanation of this in terms of wave theory should be undertaken at a future date.

Returning to the relation between shot size and amplitude, we see that if the correction to shot size for small changes in height of burst are known, and if the shot sizes are known we have three shots to work with; Baker, Charlie and Dog. For Easy shot we have

TABLE A.7

Maximum Amplitudes in Microns for "Average Charlie Shot"

Station	NORTH Z-Component	SOUTH Z-Component	X-Component	Y-Component
2	12.7	-	53.7	53.2
3	-	-	21.8	16.7
4	-	-	9.08	5.01
5	-	-	8.70	9.91
6	3.6	-	5.42	5.80
7	7.15	-	2.57	5.43
8	1.44	-	3.20	2.77
9	3.01	-	2.27	3.30
10	1.75	-	7.77	6.05
11	0.87	1.15	1.52	1.21
12	0.766	0.809	0.974	0.891
13	0.788	1.34	1.48	1.73
14	1.51	0.958	1.33	1.11
15	1.04	1.34	2.67	2.02
20	1.07	1.87	4.00	3.26
25	0.767	0.233	-	-
30	0.274	0.456	-	-
35	0.131	0.072	-	-
40	0.116	0.164	-	-
45	0.80	0.115	-	-

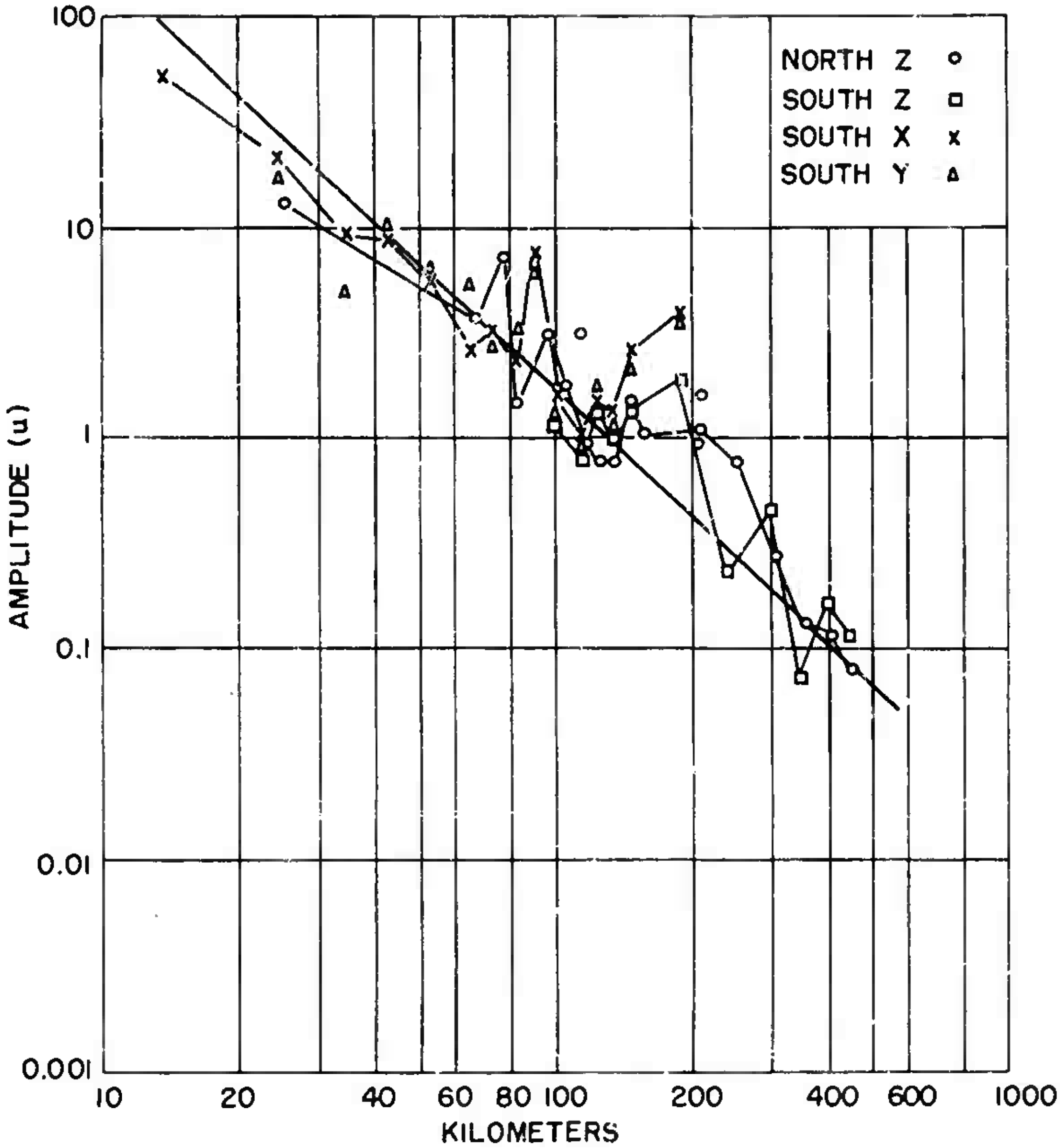


Fig. A.3 - Preliminary Plot of Amplitude vs Distance Average of Baker, Charlie, and Dog Reduced to Charlie

two corrections to make; one for change in height and one for change in shot point. The data from "average Charlie" shot should aid in obtaining a correction for distance. It can be assumed that site characteristics of the shot point and earth structure over the travel path will be much the same. For the JANGLE shots the problem becomes more complicated. Nevertheless, if a relation of shot size to amplitude for airburst has been established, and the sizes of the JANGLE shots are known then the equivalent airburst size can be estimated.

Figure A.4 shows a plot of the amplitude ratios against shot size ratio on the following basis. The amplitude ratios used were the average of the North and South line ratios for the vertical component records. The shot size ratios were obtained with respect to Charlie and Baker-to-Charlie is 0.194, Dog-to-Charlie is 1.34 and Easy-to-Charlie is 1.91. It is found that a curve representing an increase in amplitude with the 3/4 power of the shot size fits these points fairly well. The amplitude ratios for the JANGLE shots are then plotted on this curve and the equivalent airburst shot size relative to Charlie may be read. This shows Surface-to-Charlie to be 0.210 and Underground-to-Charlie as 0.245. If the amplitude values were refined and corrected as suggested above and these values used to construct a plot similar to Figure A.4, a better approximation of scaling laws would be obtained. While such an analysis would be time-consuming, it is believed that it would prove a worthwhile study.

A.8.0 ENERGY

In order to study energy relations it seemed desirable to create a statistic which would approximate seismic energy recorded at a station. The following simple statistic involving amplitude, period and signal duration was developed. An individual seismogram was divided into from three to five sections, designated by (i), which appeared to exhibit similar periods, amplitudes, or both. The period associated with the most persistent amplitudes in each section (i) was measured (designated by T_i) and a zero to peak average amplitude (designated by $\mathcal{A}_i$) was estimated for the entire section (i) in such a way that when squared it would be approximately equal to $\overline{(\mathcal{A}_j{}^2)}_i$ where j refers to one individual cycle within the section (i). The time of duration, or length, of each section was measured (τ_i) and these factors were combined thusly $\overline{(\mathcal{A}_j{}^2)_i}/T_i{}^2\,\tau_i$ and will be represented by E_i. The E_i's for the various sections of an individual seismogram were summed to obtain the statistic E. ($E = \sum E_i$) This statistic is roughly proportional to the energy activating the seismograph and should indicate a major change in period, amplitude, or duration characteristics of an individual seismogram.

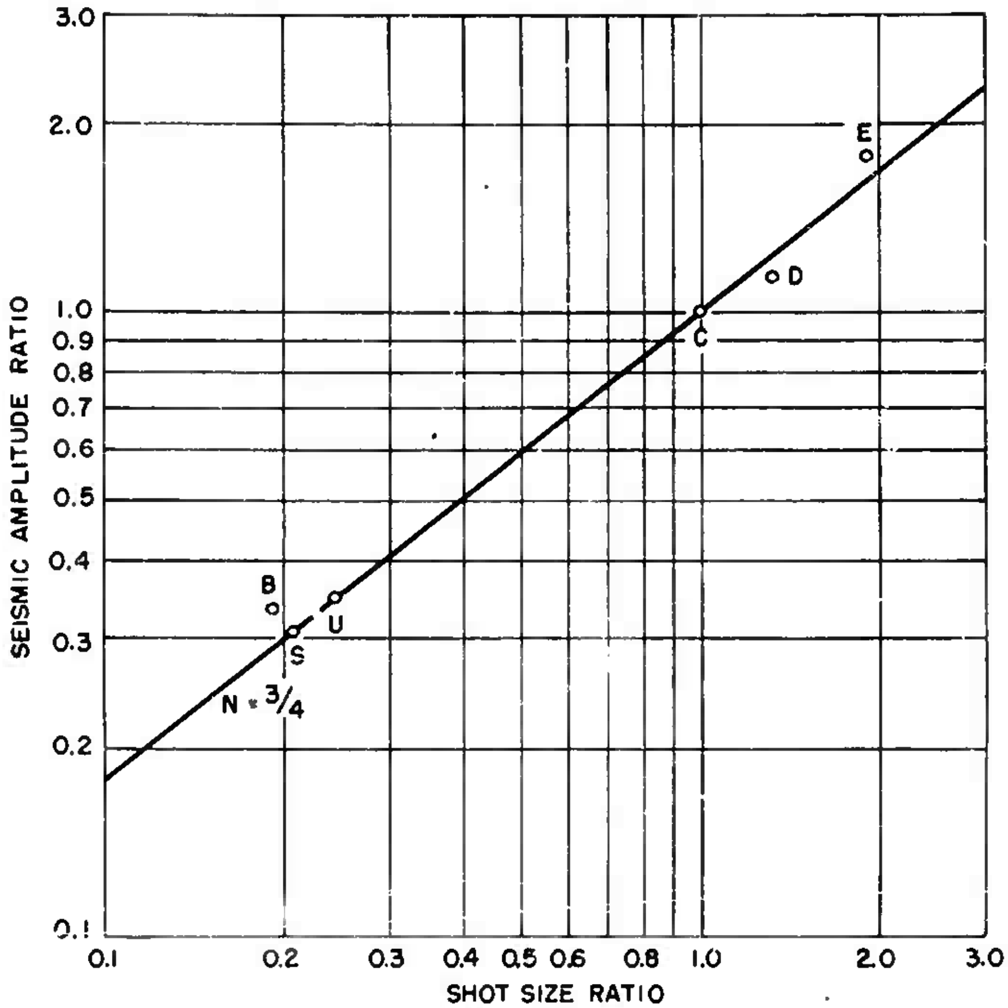


Fig. A.4 - Preliminary Seismic Amplitude Ratios vs Shot Size Ratios
(See Section A.8.0)

The statistic E as defined above has been computed for all usable records from shots Charlie and Underground and for a few stations for shots Easy and Dog. Tables A.8, A.9 and A.10 list these values. Figures A.5 and A.6 show plots of E versus distance for the vertical component of the North line for shots Charlie and Underground respectively, together with the corresponding value of maximum amplitudes squared. Both Figures A.5 and A.5 show that the amplitude squared is roughly proportional to the energy as measured by the statistic E. The ratio of E to the square of the amplitude is higher in the case of the Underground shot than Charlie. This is to be expected as the amplitude does not take into consideration the higher frequency recorded from the Underground shot. However, for these data, it seems that the maximum amplitude presents a quick way of getting a first approximation to the energy relations.

It has been suggested that the statistic E might be further refined by applying a correction dependent on the density of the media in the individual recording station area and the wave velocity in that media. This amounts to converting from energy activating the seismograph to seismic energy in the area.

A.9.0 ADDENDA AND RECOMMENDATIONS

Air wave arrivals were recorded at many stations as the acoustic wave activated the seismographs. Due to the lack of time, these arrival times could not be tabulated, nor could the wave forms be studied. It would be of interest, in future work with this data, to correlate the information from these acoustic arrivals with microbarometric data taken by other agencies during the tests.

An attempt was made to observe the phase relationship between the longitudinal and vertical traces for the first three cycles of signal at a given station for various events. Time did not permit enough analysis to arrive at any conclusions, but it is estimated that the best accuracy of measurements of phase angle from seismograms would be on the order of plus or minus 22-1/2°. It should be mentioned that the difference in instrumental phase response between a horizontal and vertical seismograph will probably be on the order of 17° for comparatively wide but operationally possible ranges in instrument parameter settings. Further work along these lines is recommended within the limitations of the data and the instrumentation as outlined above.

The analysis of the ratios of trace amplitudes of the horizontal to the vertical seismograms at individual stations for each event may lead to firmer criteria for station site location. It is believed that much valuable information as to local geologic foundations and

TABLE A.8

Computed Statistic E's for Charlie Shot *

Station	COMPONENTS X	Y	Z	COMPONENTS X	Y	Z
	NORTH			**SOUTH**		
2	-	-	234.0	-	-	-
3	-	-	-	1338.0	1270.0	-
4	-	-	-	479.8	45.11	-
5	-	-	-	225.5	284.9	-
6	-	-	38.6	157.2	119.4	-
7	-	-	120.3	31.2	216.3	-
8	-	-	10.51	152.5	73.6	-
9	-	-	31.9	41.8	33.04	-
10	-	-	13.1	367.56	209.2	-
11	-	-	6.78	5.50	8.79	8.398
12	-	-	3.05	-	-	-
13	-	-	4.72	8.36	8.85	6.23
14	-	-	11.74	10.77	6.08	3.06
15	-	-	4.15	11.42	60.32	8.09
20	-	-	4.27	10.30	42.9	13.47
25	-	-	-	-	-	-
30	-	-	0.174	-	-	0.987
35	-	-	0.159	-	-	0.0376
40	-	-	0.0135	-	-	0.0924
45	-	-	-	-	-	0.0180
	EAST			**WEST**		
11	113.27	4.721	12.71	3.415	4.721	12.71
20	2.37	3.73	4.705	-	-	-

*See Section A.8.0

TABLE A.9

Computed Statistic E's for Underground Shot *

Station	COMPONENTS X	Y	Z	COMPONENTS X	Y	Z
	NORTH			SOUTH		
2	-	-	181.6	9490.8	-	3019.4
3	-	-	-	335.66	257.24	-
4	-	-	-	253.11	98.15	-
5	-	-	-	34.59	33.89	-
6	-	-	30.2	17.50	16.59	1.324
7	-	-	11.26	5.379	2.044	-
8	-	-	5.99	21.43	14.76	-
9	-	-	8.53	14.37	7.30	6.60
10	-	-	8.24	31.98	50.68	36.73
11	14.45	15.625	1.88	13.80	11.13	4.30
12	-	-	0.470	4.612	6.793	1.705
13	-	-	1.34	4.078	4.747	2.243
14	-	-	2.73	5.150	3.765	1.166
15	-	-	0.25	32.65	1.906	1.744
20	0.929	0.572	0.20	6.916	13.64	2.965
25	-	-	0.267	-	-	0.0423
30	-	-	0.0138	-	-	0.1743
35	-	-	0.0135	-	-	0.0761
40	-	-	0.0096	-	-	0.0147
45	-	-	-	-	-	0.00178
	EAST			WEST		
11	42.03	38.1	72.67	6.18	4.89	30.1
20	0.991	1.298	0.601			

*See Section A.8.0

TABLE A.10

Computed Statistic E's for Shots Easy and Dog *

EASY			
NORTH		SOUTH	
Station	E	Station	E
N-7 z	1075.02	S-11 z	47.017
N-10 z	65.42	S-11 y	26.56
N-15 z	14.92	S-14 z	5.3837
N-30 z	1.13	S-40 z	.093
N-35 z	0.525	S-3 x	1472.04
		S-4 x	1436.40
DOG			
NORTH		SOUTH	
Station	E	Station	E
N-25 z	3.874	S-12 x	5.454
N-40 z	0.206	S-12 y	9.477
N-45 z	0.0885	S-12 z	3.52
		S-25 z	2.01

*See Section A.8.0

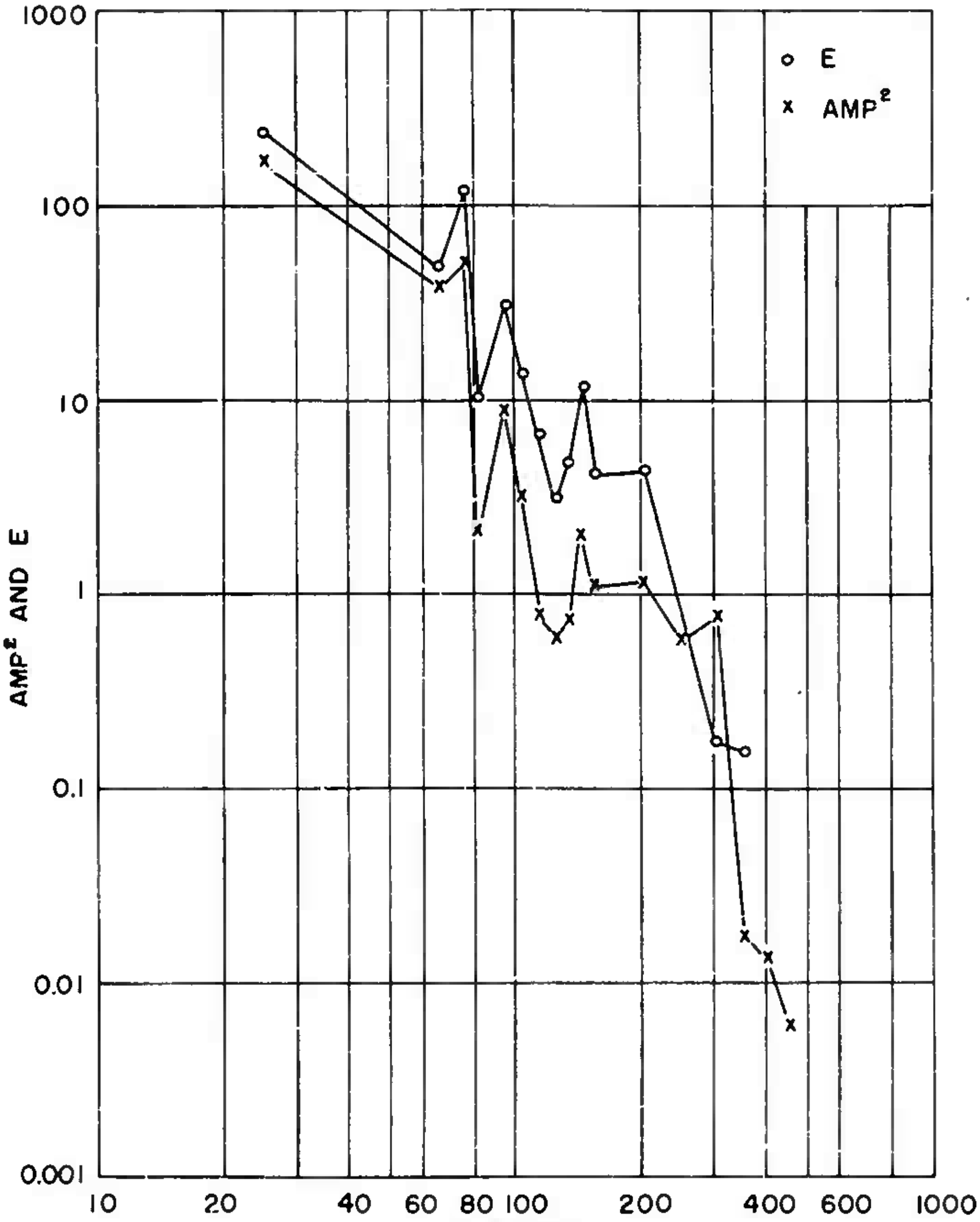


Fig. A.5 - Preliminary Plot of Amplitude Squared and E vs Distance
Charlie Shot, North Line Z Components

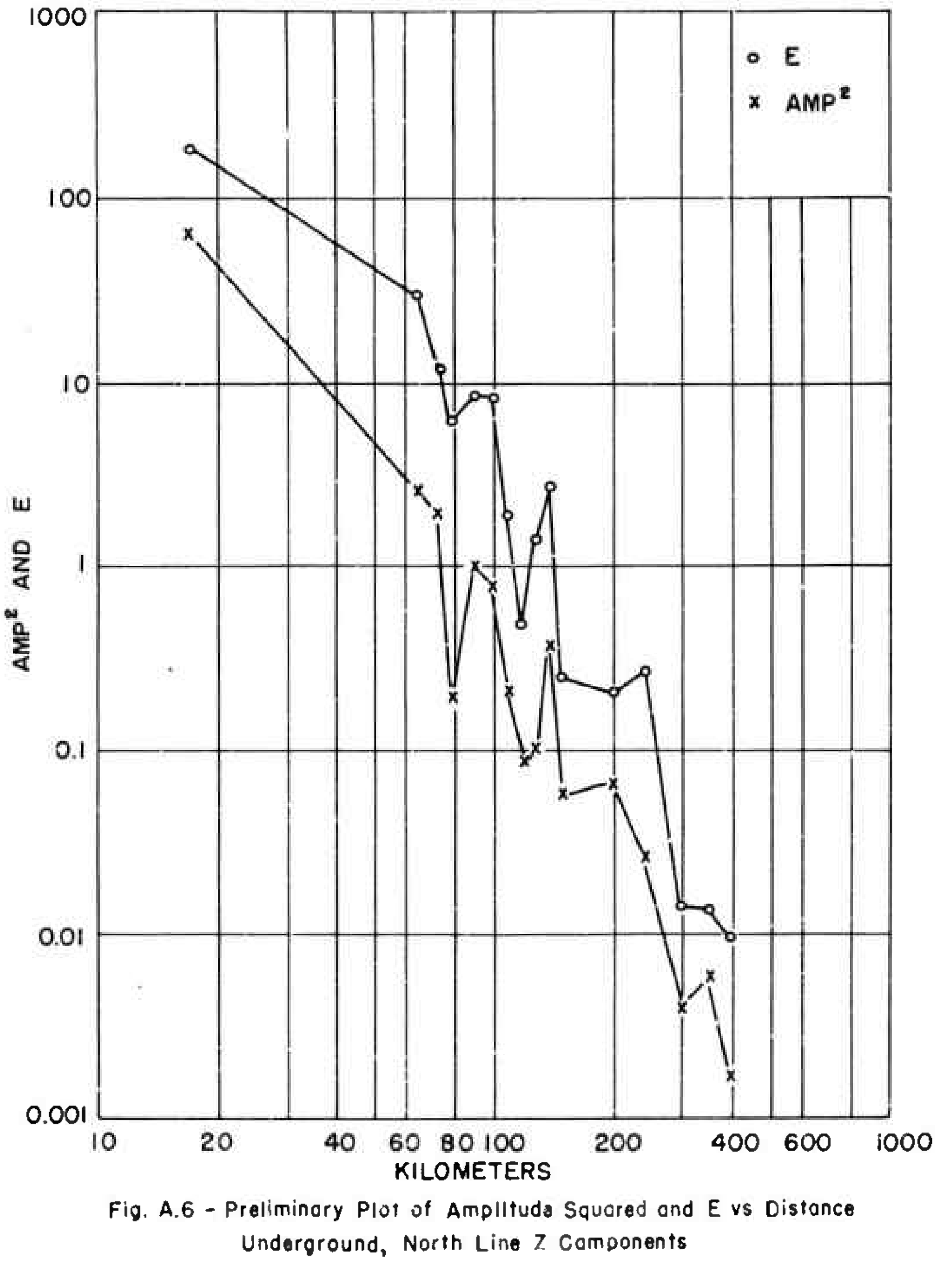


Fig. A.6 - Preliminary Plot of Amplitude Squared and E vs Distance Underground, North Line Z Components

their effective amplification or attenuation of various sections of the signals may be obtained. Time did not permit such a study during the course of analysis reported on here.

During the entire operation of the profile stations, only one or two natural seismic events were recorded, and then at only a few stations and with quite low trace amplitudes. However, what data are available should be checked for whatever comparison information may be obtained.

On the later portions of some signal runs, microseismic background was recorded with trace amplitudes large enough to permit background analysis. Further, on 13 November 1951, a full hour of background was recorded at all stations with ample trace amplitudes for analysis purposes. With stations as close together as 10 km and with a total profile length of 900 km, it should be possible to correlate a train of microseisms for the entire distance with a high degree of accuracy if cross- and auto-correlation methods are used as described in the seismic reports on Project W-29.

Approximately 400 seismograms, suitable for detailed analysis, were obtained from the profile stations. Only a general and hurried analysis has been attempted in the work reported on here and further refinement is not only desirable but necessary before definite conclusions may be reached regarding energy distribution and stratigraphy.

OPERATION BUSTER/JANGLE

PROJECT 7.2 (JANGLE)
PROJECT 7.5 (BUSTER)

U. S. COAST AND GEODETIC SURVEY

PARTICIPATION

by

D. S. Carder

15 March 1952

APPENDIX B

ABSTRACT

The U. S. Coast and Geodetic Survey participated in a strong-motion seismic survey of BUSTER/JANGLE series of explosions. Nearly 90 per cent of the energy which entered the ground as seismic waves was trapped in valley alluvium beneath the test area. Methods of energy valuation by forward and backward ray tracing agreed with an accuracy of less than a half order. An underground explosion has a relatively large shearing component, and it sends a relatively larger ratio of its seismic energy to distant localities. The periods of explosion-caused seismic waves apparently are independent of the source energy.

B.1.0 STATION DESCRIPTION

B.1.1 The U. S. Coast and Geodetic Survey occupied five stations during the BUSTER/JANGLE operations as follows:

B.1.1.1 Station $7.2A_1$ - North (hereafter known as North A)

Location - 3280 feet (1 km) S 88°W from North JANGLE Zero (hereafter known as North Zero). See Figure B.1.

Housing - Reinforced concrete shelter; inside dimensions 7.6 ft. by 10 ft; walls 14 in. thick; entrance - light trap consisting of two ships bulkhead doors; pier - circular 60 in. diameter by 20 in. high at center of and structurally separated from floor.

Underground - Desert valley alluvium probably 1500 feet or more deep.

B.1.1.2 Station $7.2A_2$ - South (hereafter known as South A)

Location - 3280 feet (1 km) S 88°W from South JANGLE Zero (hereafter known as South Zero). See Figure B.1.

Housing - Same as North A.

Underground - Same as North A.

B.1.1.3 Station 7.2B (hereafter known as B)

Location - At apex of isosceles triangle 32,800 feet (10 km) from each of North Zero and South Zero, the two zeros forming the base; on an alluvial slope on the west side of the valley. See Figure B.1.

Housing - A frame structure, provided with a light trap entrance and a 50 in. circular pier flush with the floor and at its center.

Underground - Probably fangravel.

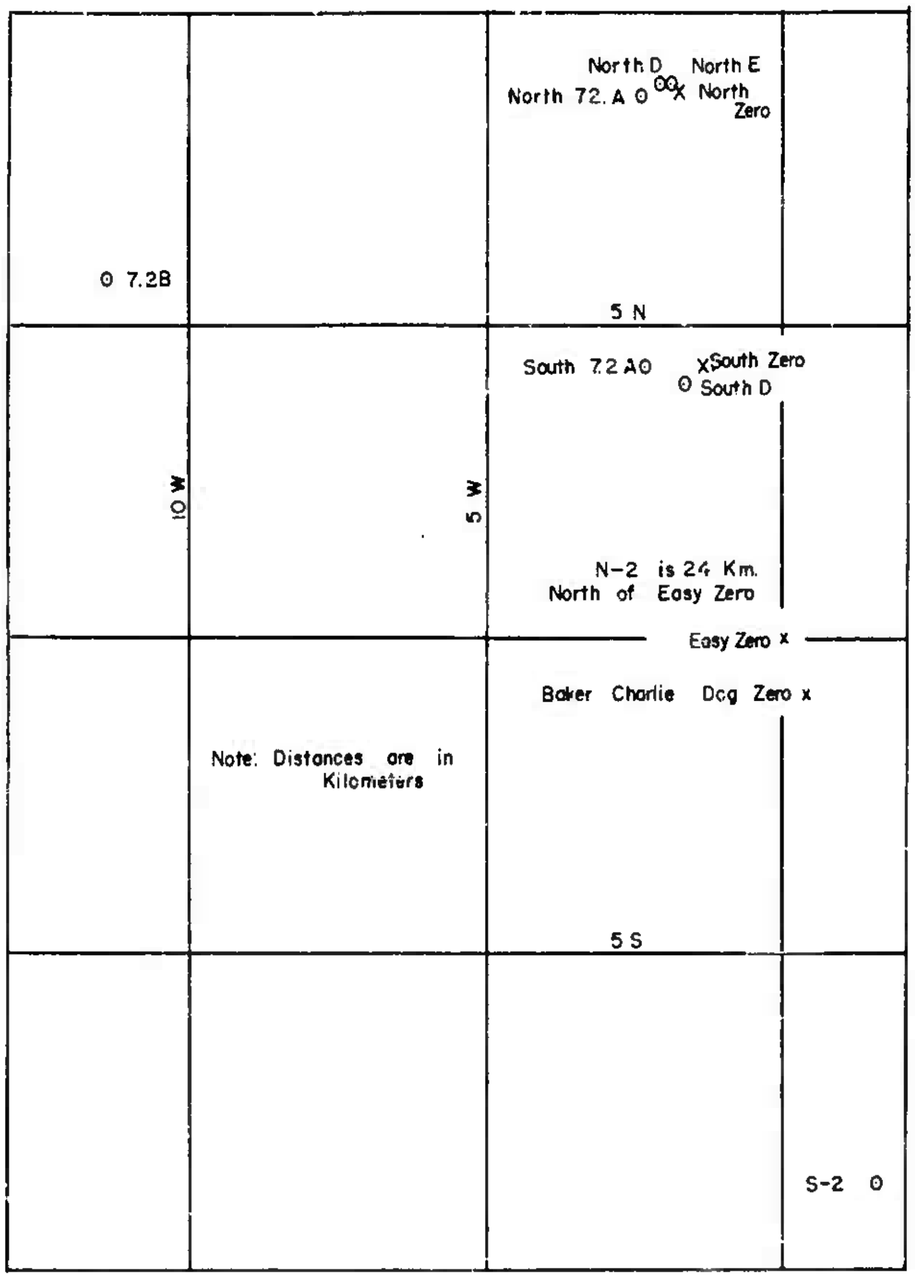


Fig. B.1 - Location of Strong Motion Stations in BUSTER / JANGLE

B.1.1.4 Station S-2

Location - South point of ridge 4.5 miles west of the entrance of the airport on Yucca Lake (dry).

Housing - A portable wooden structure with a small independent pier on one side.

Underground - Rhyolite

B.1.1.5 Station N-2

About 15 miles north of North Zero on a dense limestone outcrop.

Housing - Same as S-2.

B.1.2 Three close-in stations were occupied during JANGLE operation as follows:

B.1.2.1 Station 7.2D South (hereafter known as South D)

A buried box in valley alluvium about 1220 feet SW of South Zero. Occupied during the Surface shot only.

B.1.2.2 Station 7.2D North (hereafter known as North D) (known as 7.2E North in other reports)

A buried box in valley alluvium about 1220 feet WNW of North Zero. Designation North D used here because distance to the respective zero and instrumentation were the same as South D. Occupied during the Underground shot only.

B.1.2.3 Station 7.2C North (hereafter known as North C) (known as 7.2D North in other reports)

A buried box in valley alluvium about 1030 feet WNW of North Zero. Occupied during the Underground shot only.

B.1.3 Instrumentation

B.1.3.1 Accelerographs

Twelve-inch drum width models were employed at Stations South A, North A, B and North C consisting of one vertical (Z) and two horizontal (L and T) component accelerometers and two horizontal (L and T) small model displacement meters, all recording on the same 12-inch strip of photographic paper; paper rate 25 mm/sec; also provision for a clock trace with half-second time breaks and a fiducial trace to record on each edge of the record.

A 6-inch drum width model used successively at South D and North D provided with three accelerometers and one each clock trace and fiducial trace.

B.1.3.2 Displacement Meters

Large model, two horizontal (L and T) components at North A only.

B.1.3.3 Vibration Meters

Torsion type, horizontal components in sets of two each with 12-inch recording drum and provision for clock and fiducial traces at each edge of record strip; paper rate 20 to 25 mm/sec at Stations B, S-2 and N-2. These instruments are displacement meters for all periods up to 2.0 sec.

B.1.3.4 Tiltmeters

Moving picture camera focused on horizon at Station South A during the Underground operation. Not successful during the Surface shot.

Balanced wheel - actually with slight unbalance to yield a period of 20 sec. Used successfully at South A during Surface shot and unsuccessfully at North A during the Underground shot.

B.1.3.5 Starting Signals

Starting signals at minus 15 sec. and minus 5 sec. were provided by Edgerton, Germeshausen and Grier.

B.2.0 TEST RESULTS

B.2.1 Wave Forms

B.2.1.1 BUSTER Series

For tests Baker, Charlie and Dog, detonations occurred over the same target, and the records were very nearly facsimile of each other except that the amplitudes from successive tests were larger. The preliminary waves from Easy followed nearly the same pattern as those from earlier tests, but wave-to-wave semblance broke down almost completely in the surface group. This resulted from shifting the source position by one km. The periods of the preliminary waves were relatively long; a 1.5- to 2.0-sec period on the longitudinal component was dominant at some stations and underlay shorter period waves at other stations. The wave forms of the preliminary waves were more or less preserved from test to test and to some extent from station to station close-in, but 1.5- to 2.0-sec periods were not visually apparent in the preliminary waves on records from the Lake Mead net 160 to 216 km to the southeast. At the latter stations the dominant period was about one second in all groups although a 0.4-sec period was quite evident early on the records. At the close-in stations dominant periods in the surface wave group were from 0.8 to 1.5 sec. Waves comprising this group were quite complex. This is a characteristic of strong motion records from earthquakes. This group was formed from a compounding of several wave pulses passing the station at nearly the same time. A slight shift in the times of arrival of these pulses will create an entirely different apparent wave pattern at the close-in stations. For this reason an apparent burst of energy in the surface group does not necessarily represent the arrival of a pulse to which a travel time can be assigned.

At the Lake Mead stations, the wave pattern is less sensitive to slight shifts in source position as from Dog to Easy, a shift of about one km, or from the Surface to the Underground shot, a shift of 4.5 km. But there is a marked difference in wave pattern when there is a shift in source position of 35 km as from RANGER zero in Frenchman's Flat to the BUSTER zeros in Yucca Flat.

B.2.1.2 JANGLE Series

There is little similarity between wave forms resulting from the BUSTER and those resulting from the JANGLE series. Dominant periods near the sources of the JANGLE series are much shorter, 0.2 to 0.4 sec, and in one case at the one-km station

during the Surface shot, the highest acceleration was associated with a period as low as 0.07 sec. However, there is an outstanding characteristic which is associated with the JANGLE experiments that was also evident in the GREENHOUSE experiments: A dominant wave form was recorded at or near the beginning of the record by the displacement meters at 1000 feet from the North Zero. The period of this wave was 0.4 sec and the peak to trough displacement was 1.8 cm. This period wave carried as far as Pierce Ferry (216 km southeast). A similar wave form was recorded at a station 1.8 km from GREENHOUSE George which had a period of 1.2 sec. and which was recorded in the same form and period by Pierce Ferry more than 8000 km away.

In the BUSTER/JANGLE series, the high-frequency waves were more probably associated with source locations in reference to the surface of the ground, rather than with source energies. The higher frequencies were developed from surface or slightly sub-surface shources. The broad fronts from air sources were more conducive to development of the lower frequencies.

B.2.2 Acceleration Relationships

Table B.1 itemizes acceleration, period, distance, relationships at close-in stations. Accelerations which have the most value from an engineering point of view are those obtained from the JANGLE experiments at distances of one km or less. However, if the distance is less than 1200 feet, the shock wave arrives through the air before the ground wave has reached its maximum acceleration, after which air-coupled accelerations dominate the record for a while. Air-coupled vibrations appear also on the displacement records but do not dominate nor do they interfere materially with the general wave form.

B.2.3 Amplitude Relationships

B.2.3.1 From Direct Recording Displacement Meters

The displacement records are incomplete because at the time of the experiments a vertical motion displacement meter was not available. At the time of the JANGLE experiments the D stations were equipped only with an accelerograph, and the transverse component of the North C displacement meter apparently failed at the time the air-coupled wave arrived. Table B.2 tabulates maximum displacements regardless of wave form, together with associated periods and distances. At distances greater than four km, maximum displacements are associated with surface waves and may therefore be a combination of two or more wave pulses which are reinforcing each other.

TABLE B.1

Maximum Accelerations

Station	UNDERGROUND Distance (km)	UNDERGROUND Acceleration (cm/sec^2)	UNDERGROUND Period (Sec)	SURFACE Distance (km)	SURFACE Acceleration (cm/sec^2)	SURFACE Period (Sec)
North A	1.0	70.0	0.3	4.592	T 13 L 12	0.5 0.5
South A	4.435	10.0	0.4	1.00	L 100 (1 wave) 70 (average several waves) T 43 Z 28	0.07 0.07 0.16 0.16
B	10.0	0.5 0.5	0.25 0.5	10.0	1.0	0.25
S-2					No record	
N-2				19.1		
	DOG			EASY		
South A	5.845	10.0	0.5 to 0.6	4.97	13.0	0.8
North A	10.05	5.2	0.5 to 0.6	9.16	8.0	1.0
B	13.31	1.0+	0.6	12.60	1.4	0.7
S-2	13.50			14.40		
N-2	24.7			24.0		

TABLE B.1 (Continued)

Maximum Accelerations

Station: Shot: Distance:	Component	Ground Coupled		Air Coupled	
		Acceleration (cm/sec^2)	Period (Sec)	Acceleration (cm/sec^2)	Period (Sec)
North E Underground 0.32 km	L	294	0.25	1273	0.05
	T	98	0.15	618	0.03
	V	241	0.2	2790	0.06
North D Underground 0.37 km	L	362	0.15	807	0.04
	T	87	0.22	716	0.05
	V	181	0.23	1010	0.04
South D Surface 0.037 km	L	641	0.13	1455	0.03
	T	290	0.14	1604	0.03
	V	502	0.04	-	-

TABLE B.2

Maximum Displacement

Station	UNDERGROUND			SURFACE		
	Distance (km)	Displacement μ	Period (Sec)	Distance (km)	Displacement μ	Period (Sec)
North A	1.0	1700 T 1500 L	0.5 (1 wave) 0.3 (several waves)	4.592	800	0.5
South A	4.435	500 300	0.6 0.5	1.0	1400 L 500 L 1300 T	.7 1.2 0.2
B	10.0	55 L	.75 (after 15 sec)	10.0	65 L 55 T	0.6 1.2
S-2		37	1.0	No	record	
N-2		5	1.0 0.5	19.1	6	1.0
North E	0.32	9000 L	0.4			
	DOG			EASY		
South A	5.845	900	● 1	4.93	1500 T 1500 L	0.8 ● 1.0
North A	10.05	1000	1.0	9.16	1500 L (2 waves) 1800 T (1 wave)	0.8to 1.0 0.8to 1.0
B	13.31	170	0.8	12.60	300 L 245 T	1.0 1.5
S-2	13.50	200	1.1	14.40	330 L (after 22 sec) 280 T (after 26 sec)	1.2 1.2
N-2	24.7	33	1.3	24.0	● 40	1.3-

B.2.3.2 <u>From Integration of Accelerograph Records</u>

The accelerograph records will eventually be integrated once and twice to obtain instantaneous molar velocities and displacements, the latter which will be tested against directly recorded displacements where such are available. Such information is not at present available.

B.2.3.3 <u>From a Long-Period Displacement Meter</u>

A long-period displacement meter (T_0 10 sec) was installed at Station North A for the purpose of (a) checking intermediate period meters having about the same magnification; and (b) for testing the presence of long-period waves to which the intermediate period instruments are relatively insensitive. Results: (a) the two types of instruments produced identical records and (b) no periods longer than one or two seconds were evident.

B.2.3.4 <u>Amplitude Variation According to Source Energy</u>

BUSTER Operations

Since the records from tests Baker, Charlie and Dog are almost exact replicas, and since Stations B, S-2 and N-2 were equipped with direct-recording displacement-type seismographs, records from these stations will be used in direct amplitude-energy relationships between Baker, Charlie and Dog. Table B.3 lists the amplitudes of certain selected waves which retained the same form from test to test. Amplitude relationships between Baker, Charlie and Dog did not deviate very far from the ratio 1:2.75:3.2. Using the maximum wave alone, the ratio is 1:2.8:3.15. At Station B a comparison will be made of preliminary waves from tests Dog and Easy, since these are the only waves which retained their form from test to test. A weighted average of several waves which were carried through both tests is respectively 25μ and 39μ.

Allowing for the lesser distance to the Easy zero, 12.6 km as compared with 13.3 km to the Dog zero, comparative amplitudes would probably be more nearly 25μ : 37μ ; and the comparative amplitudes resulting from the respective BUSTER drops would be 1:2.75:3.2:4.7. Yields submitted by the Atomic Energy Commission have the ratio 1:5.16:6.85:9.85. The exponential scaling law between energy yields and corresponding amplitudes is 5:3 between Baker, Charlie and Dog and 3:2 between Dog and Easy. These measurements were based on records from instruments which have high fidelity in measuring

TABLE B.3

Amplitude Measurements for Tests Baker, Charlie and Dog

Wave Description	Period (Sec)	Trace Double Amplitude (MM)			Ratios - B-1		
		B	C	D	B	C	D
		STATION B					
P Group L	1.5	1.5	3.7	4.6	1	2.5	3.0
S? Group T	1	1.3	3.8	4.8	1	2.9	3.7
P_2 Group L	1	3.0	8.1+	9.4	1	2.7	3.1
S or S_2 Group T	1.1	2.7	7.2	8.7	1	2.7	3.2
R Group L	1	7.0	20.8	26.0	1	3.0	3.7
15 Sec Group L	1.3	10.5	28.5	33	1	2.7	3.1
19 Sec Group T		10	27	27	1	2.7	2.7
20 Sec Group L		16	44	50	1	2.7+	3.1
				Seismic Energy	1	8	10
		STATION S-2					
P Group T	0.2	.3	.9	1.1	1	3	3.7
P Group L	1.7	1.0	2.8	3.5	1	2.8	3.5
S First Motion T		0.8	2.4	3.0	1	3	3.8
15 Sec Group L	1.2	4.7	13.0	15.6	1	2.8	3.3
21 Sec Group T	1.1	12.6	33	38.5	1	2.6	3.1
26 Sec Max Group T		19	48.8	58.8	1	2.6	3.1
26 Sec Max Group L		9.5	24.5	31.5	1	2.6	3.3
				Seismic Energy	1	7	10
		STATION N-2					
P Group L	2.0		1.1	1.3			3.3
15 Sec Group T	2.0		4.3	5.2			3.4
20- Sec Group T	1.3		6.7	8.1			3.4
20 Sec Group T		2.6*	7.3	8.7	1	2.8	3.3
21 Sec Group L	1.4		3.2	3.6			3.1
				Seismic Energy	1	8	10

* Only wave recognizable

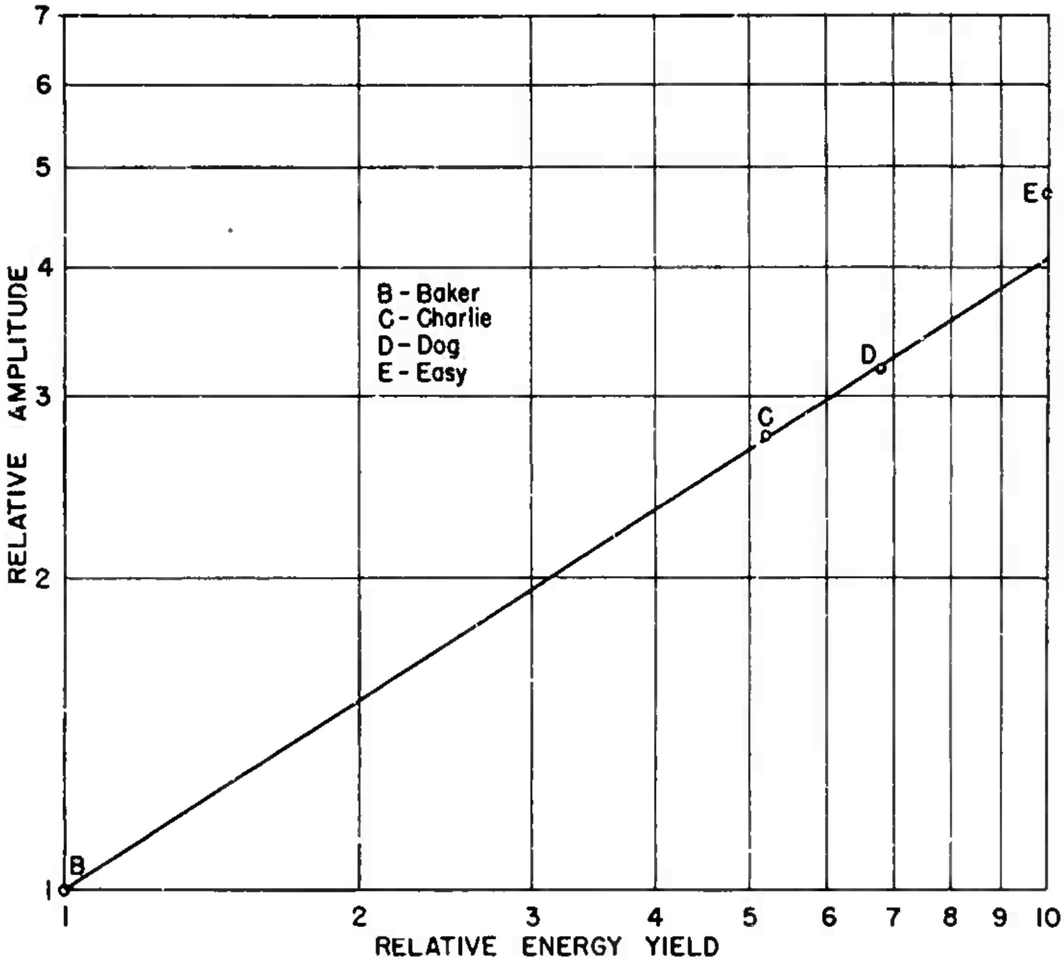


Fig. B.2 - Recorded Seismic Amplitudes vs. Eomb Yield

ground amplitudes of the waves in the frequency range generated by these explosions.

Several waves which were carried through from test to test on the N-S component at Pierce Ferry and the E-W component at Boulder City were measured and their relative weighted amplitudes were computed. They are 1:2.7:3.0:4.1 at Pierce Ferry and 1:2.8:3.2:4.8 at Boulder City. The latter more nearly correspond to results from the close-in stations.

JANGLE Operations

Since there is no wave-to-wave correspondence between the BUSTER/JANGLE operations, an application of an exponential scaling law between energy yield and ground amplitude at any one of the close-in stations would be unsound. The only sound comparison available is the amplitude relationships between the Surface and Underground tests. Station B is equidistant from both tests (10.0 km) and nearly the same maximum ground amplitude of about 50 μ was obtained from both tests.

At Pierce Ferry, the picture is different. On the N-S component the wave-to-wave amplitude relationship between the Underground and Surface shots, where it exists, is more nearly 2.5 to 1. Between the Underground and Surface shots there is no wave-to-wave amplitude relationship, but the envelope amplitude relationship between the Underground shot and Baker is 5 to 3 in the S group and 5 to 4 in the P group which indicates that shearing action is more dominant in the underground experiment. Similar results are obtained from a comparison of Boulder City N-S records.

B.2.4 Energy Distribution

B.2.4.1 Energy which enters the ground as seismic waves may be fairly accurately evaluated using data from close-in stations; and less accurately from stations at some distance. Energy density of a train of seismic waves crossing unit area under the station is given by

$$E_e = 2\pi^2 \rho \sum \lambda_i A_i^2 / T_i^2 \qquad \text{(B.1)}$$

where ρ = density of the underlying rock,
λ_i = $V_i T_i$ is the length of an individual wave of a train,
A_i is its zero to peak amplitude, and
T_i is its period.

The subscript s designates the station in general. For a particular station, the station initials will be used as a subscript.

Total energy entering the ground from the source is given by

$$E = A_s \cdot Q_s \cdot E_s \qquad (B.2)$$

where A_s is the area of the wave front in the form as it leaves the source extended to the distance r from source to station,

and Q_s is a factor containing the amount of scatter of the wave front, and loss by absorption and refraction.

Usually the factor Q_s contributes most to inaccuracies in evaluating seismic energy at the source.

B.2.4.2 <u>Seismic Energy at the Source from the Underground Test</u>

<u>Data from North E</u>: A fairly high degree of accuracy is possible by using data from this station because a hemispherical wave front from source to station can be assumed and ground amplitudes may be measured directly.

From the longitudinal component displacement meter record, $A = 0.9$ cm of one wave and 0.4 cm of a second wave after which the trace dies out. Assume energy is divided equally among the three components, that average wave velocity in the surface material is one km/sec and average density is two, then

$$E_E = 3\left[2\pi^2 \rho v \sum \frac{A^2}{T}\right] = 3\left[2\pi^2 \cdot 2 \cdot 10^5 \left(\frac{0.8}{0.4} + \frac{0.16}{0.4}\right)\right] = 10^{7.5} \qquad (B.3)$$

If r = .32 km,

$$A_e = 2\pi r^2 = 10^{9.8} \text{ sq. cm}; \qquad (B.4)$$

and if Q_e is the absorption factor in the surface alluvium,

$$E = Q_e \cdot A_e \cdot E_e = Q_e \times 10^{17.3} \text{ ergs.} \qquad (B.5)$$

<u>Data from North A</u>: On the longitudinal displacement record at North A, $\sum A^2/T = 16 \times 10^3$ and using same reasoning as above

$$E_a \quad 2\pi^2 \rho v \sum A^2/T = 10^{6.3} \qquad (B.6)$$

and if $r = 1$ km

$$E = Q_s 10^{17.1} \tag{B.7}$$

comparing with the above equation B.5

$$Q_s = 10^{0.3r} \tag{B.8}$$

where r is in kilometers. This means that absorption of a 0.4-sec period wave in the valley alluvium is by a factor of two for each kilometer of increase with distance, and seismic energy at the source is

$$E = 10^{17.4} \text{ ergs.} \tag{B.9}$$

Data from Station B: At Station B, $4\frac{1}{2}$ waves having a period of 0.63 sec are believed to belong to the direct P group through the valley alluvium traveling at an average speed of about 1.8 km/sec. The average amplitude of these waves is 25 μ and $\sum A^2/T = 4 \times 10^{-5}$. Assuming that these waves represent a third of the energy on each component or a ninth of the total at the station

$$E_B = 9 \cdot 2\pi^2 \rho v \sum A^2/T = 2600 \tag{B.10}$$

Assuming that most of the seismic energy is trapped in the valley alluvium which has an average thickness h 0.7 km and since r 10 km

$$E = 2\pi r h Q_B \cdot E_B = Q_B \cdot 10^{15} \text{ ergs.} \tag{B.11}$$

If $E = 10^{17.4}$ ergs, $Q_s = 10^{.24r}$ which is to say that absorption of a 0.6 sec P wave in the valley alluvium is by a factor of almost two for each kilometer of increase with distance.

Data from Hoover Dam: Hoover Dam is equipped with an EW component direct recording Wood-Anderson seismograph. The record of the Underground shot is very small but measurable. Prevalent periods are 0.4 and 1.0 sec and trace amplitudes are about 0.2 mm. Magnification of a one-second period wave is about 750. Evaluating energy contained in the one-second period alone, at the station using $\rho = 3$ and average $v = 3$ km/sec

$$E_{H_{(T=1)}} = 3 \cdot 2\pi^2 \rho v \sum A^2/T = 1.5 \text{ erg/sq.cm.} \tag{B.12}$$

The summation is over 40 waves having a one-second period. An earlier determination of energy absorption of a one-second wave in the earth's crustal layers was by a factor of $10^{.0043r}$. The distance r of Hoover Dam is about 170 km. Assuming that about half of the energy that gets into the so-called crustal layers from the alluvial valley is trapped

there, and that the thickness of these layers is 30 km, the total energy contained in one-second periods that escapes from the valley is

$$E_{1.0} = 2 \cdot 2\pi rh\, E_H \cdot 10^{0.7} = 10^{15.7} \text{ ergs.} \quad (B.13)$$

Data from Pierce Ferry: The Pierce Ferry Benioff short period N-S is used in this study because its setting has remained unchanged through the more recent A-bomb tests. The S-1 blow up magnification of a 0.4-sec and a one-second wave is about 40,000. Twenty-five waves in the $\overline{S}$ group have a 0.4-sec period and contain about half of the energy on the trace. The average trace amplitude squared is 1.25 cm^2 and

$$\sum A^2/T = 5 \cdot 10^{-8} \quad (B.14)$$

If $\rho = 3$ and $v = 3$ km/sec

$$E_\rho = 6 \cdot 2\pi^2 \rho v \sum A^2/T = 5 \text{ ergs/cm}^2 \quad (B.15)$$

The distance to Pierce Ferry is 216 km, the estimated absorption is $10^{0.9}$ and

$$E_{0.4} = 2 \cdot 2\pi rh\, E_\rho \cdot 10^{0.9} = 10^{16.5} \text{ ergs} \quad (B.16)$$

which is an estimate of energy contained in waves having periods of 0.4 sec which reaches the basement beneath the zero area. Comparing this with the initial seismic energy at the source of $10^{17.4}$ ergs, we have a factor of

$$10^{16.5-17.4} = 10^{-.9} = 0.12. \quad (B.17)$$

This is the estimated ratio of energy which escapes from the valley.

Energy loss to Station N-2: Ground motion at N-2 resulting from the Underground shot is relatively very small. A geophysical survey of the area reveals a buried ridge a few thousand feet north of North Zero covered by about 600 feet of sediment. This ridge and perhaps the structure north of the basin presumably trap a relatively large amount of energy which would otherwise reach a station north of the area.

B.2.4.3 Seismic Energy at the Source from Test Easy

Data from North A and South A: Strong surface waves from the BUSTER tests were recorded at each of these stations. It will be assumed that they traveled as a ground roll in the valley alluvium at a speed of 0.6 to 0.75 km/sec, and that the

thicknese of the alluvium along the paths of travel is 0.4 km. At each station $\sum A^2/T = 4 \times 10^{-2}$ but the wave speed to North A is slightly higher. Evaluating: $E_{na} = 6 \times 10^5$ and $E_{sa} = 7 \times 10^5$ assuming that about half of the energy is in the large surface waves. Evaluating seismic energy at the source, where the respective distances are 9 km and 6 km

$$E = Q_{na} \times 10^{17.1} = Q_{sa} \times 10^{17.0}. \qquad (B.18)$$

The Q's take care of absorption, but evidently it is less to North A than to South A.

Data from Pierce Ferry: Evaluating the energy in one-second period waves of the S group, a summation of 18 waves which contain about half of the energy on the N-S record, gives the value of $\sum A^2/T = 12 \times 10^{-8}$ and the energy delivered to the rock beneath the base of the alluvium near the source is evaluated at $E_{1.0} = 10^{17.0}$ ergs. Similar data from Hoover Dam give practically the same results. Total energy yielding this period at the source probably is about eight times this amount or $10^{17.9}$ ergs. A 0.4-sec period rides on longer period waves at Pierce Ferry. Amplitudes of these waves are difficult to measure, but it is believed they contain nearly as much energy as the longer waves or very nearly $10^{17.0}$ ergs at the base of the alluvium and $10^{17.9}$ ergs at the source. The total Easy seismic energy is therefore very nearly $10^{18.2}$ ergs, or about seven times that of the Underground shot.

B.2.4.4 Seismic Energy from the Surface Test

Data from Pierce Ferry - NS: The 0.4-sec period is dominant in the $\overline{F}$ group and subordinate in the $\overline{S}$ group. The trace amplitude of waves having this period is somewhat less than a third of that of similar waves from the Underground shot, indicating that the surface test delivered less than a tenth of the amount of energy to distant points in the form of 0.4-sec periods than did the underground test.

One-second periods dominate the main part of the record. Using the same reasoning as heretofore and the basis that seismic energy contained in one-second periods is measured from 50 waves having a trace amplitude of 55 mm, we have in the basement beneath the source $E_{1.0} = 10^{15.5}$ ergs, which is about that delivered by the underground test.

B.2.4.5 Comparison of BUSTER/JANGLE Seismic Energy

From the preceding section it was shown that the Surface shot delivered about $10^{15.5}$ ergs and Easy about $10^{17.0}$ ergs to the basement in the form of one-second period seismic waves. The Underground shot delivered about $10^{15.5}$ ergs. The energy ratio in the form of one-second periods from the JANGLE series in regard to Easy is on the order of 1:30. This is about the same seismic energy ratio as Baker to Easy. It follows that the ability of the JANGLE series to produce one-second waves was nearly of the same order as that of Baker. However, since the total seismic energy in Easy was about seven times that of the Underground shot, the total seismic energy delivered by the latter was nearly of the same order as that delivered by Charlie.

B.2.5 Seismic Wave Velocities

B.2.5.1 Wave Speeds in the Source Area

The initial wave front from the JANGLE zeros to the one-km station had an average speed of 1.25 km/sec. This is largely in the upper part of the alluvium.

The P-wave group through the alluvium to the B station from both JANGLE and BUSTER zeros is about 2.0 km/sec.

The P-wave speed in the basement is about 50 km/sec under the valley and 5.2 km/sec along the east edge. The arrival of a wave through this medium to the B station is delayed more than 0.1 sec compared with that of the A stations and S-2. This is probably because of the relatively greater thickness of alluvium in the center of the valley under which these waves must pass; and partially to the greater elevation of the B station.

The P-wave speed in the sub-basement, based on the indefinite location of Station N-2 is 6.5 to 6.8 sec.

B.2.5.2 Wave Speeds in the Lake Mead Area

Using U. S. Coast and Geodetic Survey stations which are operated on a continuous basis in the Lake Mead area, the P speed is about 6.2 km/sec. The distance to these stations is from 160 to 215 km.

Data from the Lake Mead stations alone indicate a speed of about 8.1 km/sec in the mantle.

B.2.5.3 Layer Thicknesses

Travel time data will be applied to a formula

$$t_0 = \frac{\sum 2h_i \cos \theta_i}{v_1} \qquad (B.19)$$

where h_i is the thickness of a layer,

$\theta_i = \sin^{-1} \frac{v_1}{v_{n+1}}$

v_{n+1} is the speed beneath the lower layer evaluated,

and t_0 is the time axis intercept of the extended travel time curve corresponding to the layer under equestion.

Travel time data on the east side of the valley are represented by the curve $t = 0.6 + \frac{\Delta}{1.25}$ where time is in seconds and Δ is distance in kilometers; $v_1 = 1.25$ and $v_2 = 5.2$. Solving for h_1; $h_1 = 0.4$ km, which is the thickness of the alluvium along the east side of the valley.

Across the valley to Station B we have

$t = 0.7 + \frac{\Delta}{2.0}$ and $v_2 = 5.0$. Solving: $h_1 = 0.75$ km, which is the thickness of the alluvium across the valley.

Travel time in the basement is represented by $t = 1.2 + \frac{\Delta}{5.2}$ on the east side of the valley and $t = 1.2 + \frac{\Delta}{5.0}$ beneath the valley.

Solving for h_2: $h_2 = 1.9$ km under the valley and 2.3 km beneath the east side.

The sub-basement in which the speed is 6.0 to 6.8 km/sec is beneath the basement. Combining the above data with Lake Mead data alone, the top of the mantle lies at a depth of 30 to 35 km.

B.2.6 Application of Geometric Optics to Transfer of Energy

The speed of compressional waves near the bottom of the alluvium in Yucca Flat is about 2 km/sec. If the average speed in the basement is 5.2 km/sec and 6.5 km/sec in the sub-basement, and assuming that energy transmission follows the laws of geometric optics, we have from Snell's law

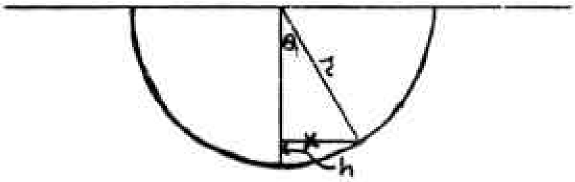
$$\frac{v_1}{v_2} = \frac{\sin \theta_1}{\sin \theta_2} = \frac{2}{5.2} \qquad (B.20)$$

and

$$\frac{v_1}{v_3} = \frac{\sin \theta_1}{\sin \theta_3} = \frac{2}{6.5} \qquad (B.21)$$

where the subscript 1 refers to the alluvial layer,
2 refers to the basement and
3 refers to the sub-basement.

It is immaterial if other layers intervene. At critical incidence on the top of the basement, $\sin \theta_2 = 1$ and $\sin \theta_1 = 2/5.2$. If the base of the alluvium is a level surface, most of the energy contained in the vertical cone which has a half angle θ_1 at the apex, where $\theta_1 = \sin^{-1} 2/5.2$ will reach the basement, and the remainder will be trapped in the alluvium. Energy which reaches the sub-basement, hence the out-lying seismograph stations, will be confined to the cone having a half angle at the apex of $\theta_1 = \sin^{-1} 2/6.5$. In the diagram



consider a hemispherical wave front of radius r. The area of the hemisphere is $2\pi r^2$ and the area of the zone subtended by $x = r \cdot \sin \theta_1$ is $2\pi rh$ where $h = r - \sqrt{r^2 - x^2}$. If source energy is equally distributed over the hemispherical front, and if θ_1 is the angle of critical incidence at the interface, all energy except that distributed over the zone with height h is trapped above the interface. We can use any unit for x and r. Suppose we use the respective wave speeds in the strata under consideration. Now for uniform energy distribution

$$\frac{\text{Energy at the source}}{\text{Energy to the sub-stratum}} = \frac{\text{Area hemisphere}}{\text{Area zone}} = \frac{r}{h} \qquad (B.22)$$

This neglects loss by absorption and reflection.

If the basement speed is 5.2 and $v_1 = 2$ $\quad h = 5.2 - \sqrt{5.2^2 - 4} = .4$ and $r/h = 13$.

If the sub-basement speed is 6.5, $h = 6.5 - \sqrt{6.5^2 - 4} = .32$ and $r/h = 20$.

If the laws of geometric optics are strictly applicable and if the interfaces are flat surfaces, it follows that more than 90 per cent of the initial seismic energy was trapped in the surface alluvium, and only about five per cent penetrated the sub-basement. Applying rough ray tracing methods to data from the Lake Mead stations it was estimated that about 12 per cent of the initial seismic energy from the underground explosion had entered the sub-basement. This is a fair check of the accuracy of the methods used. In one case estimated energy reaching a distant station was traced to a region in the sub-basement beneath the zero area, and in the other case, source energy was traced to the same region.

B.3.0 CONCLUSIONS

The following conclusions are derived from strong motion studies of the BUSTER/JANGLE series of explosions in Yucca Valley, Nevada and from data from seismograph stations in the Lake Mead area.

(a) Dominant seismic waves from an A-bomb explosion are fairly simple in form about 1000 feet from the source. They are complex in form from several thousand feet to several miles from the source probably because of multiple reflections within the surface strata. They are less complex a hundred miles or more from the source.

(b) Periods of these waves range from 0.07 to 2.0 sec but periods of 0.25 to .60 sec and 0.9 to 1.3 sec prevail in the source area. A 2.0-sec period compressional wave is also evident near the source area. From a casual inspection of the records, periods of 0.4 sec and 1.0 sec are the most dominant 150 km to 216 km from the source. However, a more detailed analysis of a record from Pierce Ferry (Underground shot distance 216 km) indicates three wave groups having periods of 0.5, 0.9 and 1.3 sec. The shorter period waves are produced in relatively greater abundance by the surface and underground explosions.

(c) The period apparently is independent of source energy.

(d) Wave forms may be reproduced by using the same ground zero, but a shift of ground zero by as little as one km will materially change the wave form pattern, especially of surface waves.

(e) Ground amplitudes vary as the 3/5 power of energy yields in high air bursts.

(f) Shearing action was stronger from the underground explosion than from either the surface or air bursts.

(g) Seismic energy from the underground explosion was evaluated at $10^{17.4}$ ergs, and the estimated seismic energy from the East burst was $10^{18.2}$ ergs.

(h) Nearly 90 per cent of the seismic energy from the underground explosion was trapped in the alluvial fill of the valley, and energy absorption in that fill was very high.

(i) By a comparison of seismic energies resulting from the surface and the underground explosions it is found that:

(1) The two shots yielded about the same amount of energy to the valley alluvium, but

(2) The underground explosion sent several times more energy to distant stations than did the surface shot. This is probably because ground shock wave from the underground test penetrated deeper into the higher speed layers of the alluvium.

(j) The estimated thicknesses of strata beneath the test area are

(1) 0.4 to 0.7 km of valley alluvium associated with speeds 1.2 to 2 km/sec,

(2) 2 km of basement rock associated with speeds of 5+ km/sec,

(3) 30 km of sub-basement rock associated with speeds of 6.0 to 6.8 km/sec.

OPERATION BUSTER/JANGLE

PROJECT 7.2 (JANGLE)
PROJECT 7.5 (BUSTER)

BEERS AND HEROY PARTICIPATION

by

SECTIONS C.1 and C.2
William B. Heroy

SECTIONS C.3, C.4 and C.5
Carl F. Romney

20 January 1952

APPENDIX C

0.1.0 INTRODUCTION

0.1.1 Purpose

The purpose of this report is to furnish information concerning the work performed under this contract during the period of field operations commencing in August 1951, and terminating 30 November 1951. The letter of authorization to commence work on the contract, dated 24 August 1951, specified that a report of forecast results should be delivered on or before 15 September 1951. It was contemplated that this report would include a sketch of each station layout and of the equipment installed in each. Inasmuch as the work of selecting the station sites and installing the equipment was not completed on that date the information for the preparation of a forecast report was not available. This information has accordingly been incorporated in the present report of preliminary results.

0.1.2 Scope

The Statement of Work is annexed to Contract AF33 (600)-5978 as Exhibit "A" and reads as follows:

"1. Equip, establish, staff and supply seismic research stations at the sites selected by other means in the vicinity of Ft. Sill, Oklahoma, and Dobbins Air Force Base, Georgia.

"2. Rehabilitate GREENHOUSE (Unclassified) stations located near Douglas and Encampment, Wyoming, incorporating changes indicated as desirable by GREENHOUSE operations and changes necessary for year around operations.

"3. Operate the stations referred to in 1 and 2 above during the period of Operations JANGLE and BUSTER. Estimated dates of these operations are from 1 October 1951 through 30 November 1951.

"4. Analyze the records obtained from the operations in 3 above, together with copies of records to be furnished by Headquarters USAF (AFOAT-1) from coordinated projects.

"5. Submit a report which will include:

"a. Results of the analyses in 4 above.
"b. A sketch of each station layout

"c. A description of the station operation and equipment.
"d. An evaluation of the results of the operation in the light of the AFOAT-1 mission.
"e. Conclusions drawn from this operation.

"6. Provide for the transfer of selected equipment from earlier Beers and Heroy and/or Geotechnical Corporation contracts and for the shipment of said equipment to field locations designated by the contractor.

"7. Reports.

"a. Forecast.
"b. Preliminary.
"c. Final."

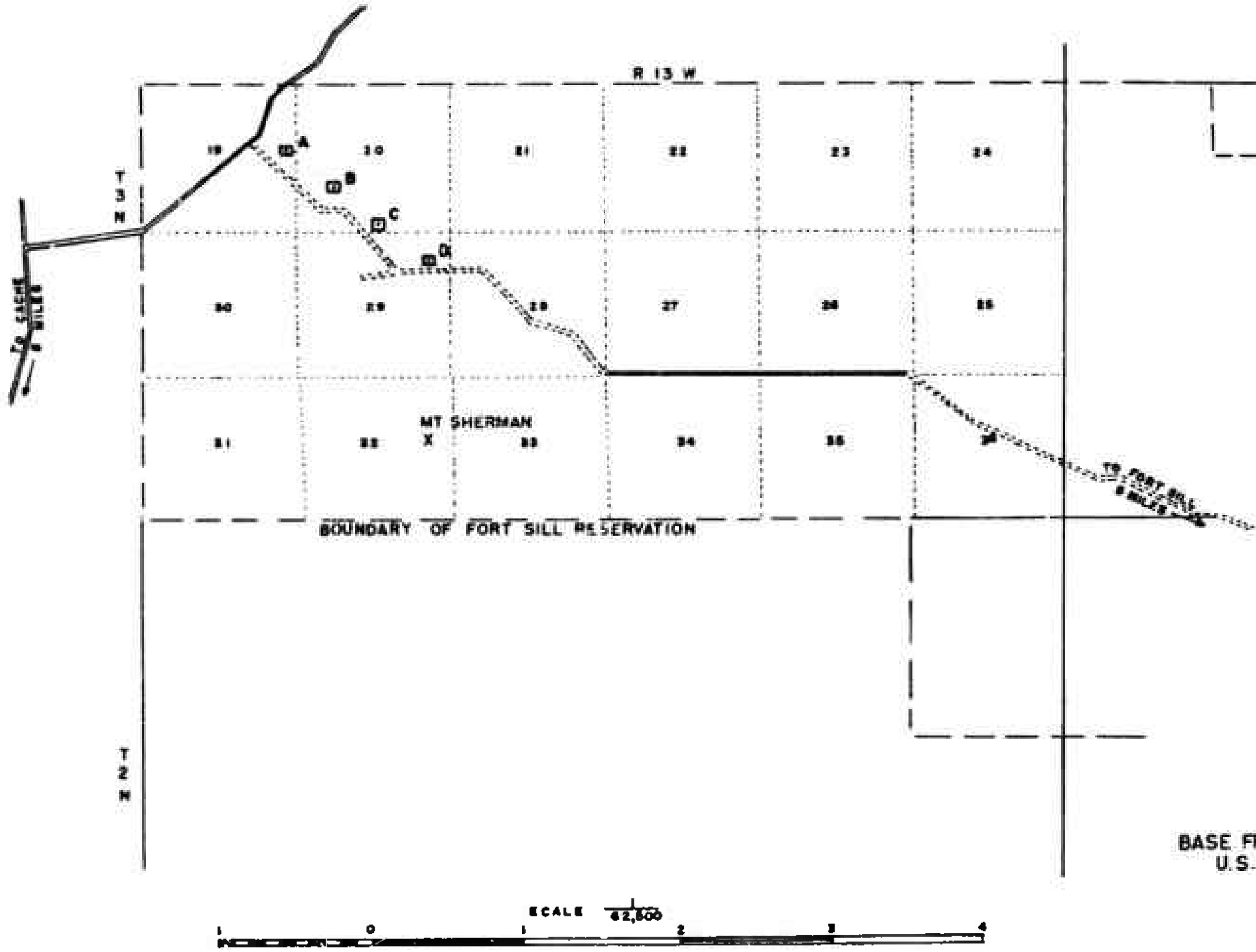
This preliminary report describes the work performed on the equipment and in the rehabilitation of stations specified in Items 1 and 2; the operations carried on pursuant to Item 3; and the preliminary results of the analysis of records directed by Item 4. It relates to the installation of two additional stations at Ft. Sill, Oklahoma, (Area 11) and Fort McClellan, Alabama, (Area 12); the rehabilitation of stations near Encampment, Wyoming (Area 5), and Douglas, Wyoming (Area 6); the operation of these stations during the JANGLE and BUSTER tests; and a preliminary report on the seismic results obtained.

C.2.0 LOCATION AND EQUIPMENT OF STATIONS

C.2.1 Installation of Station at Fort Sill, Oklahoma

Fort Sill Military Reservation is situated immediately north of the city of Lawton, Comanche County, Oklahoma. Fort Sill is the location of the Artillery School of the United States Army. The Reservation is about 20 miles in extent from east to west and about eight miles from north to south. Its western part lies in the Wichita Mountains. The elevation ranges from 1100 to 2207 feet, the highest point being Mount Sherman. U. S. Highway 277 and the Chicago, Rock Island and Pacific Railroad extend north and south through the Reservation, dividing it into two areas, the East Range and the West Range.

The rocks of the East Range are of sedimentary origin. In the West Range both sedimentary and igneous rocks are present, the latter being Pre-Cambrian granite and forming the core of the Wichita Mountains. The granite is generally well exposed and not deeply weathered.



BASE FROM CACHE QUADRANGLE
U.S. GEOLOGICAL SURVEY

Fig. C.1 Sketch Map Showing Location of Seismic Station, Fort Sill, Oklahoma

A preliminary survey was made in the area under authority of Contract AF33 (038)-17730, Amendment 1, from August 9 to August 30, for the purpose of determining the level of microseismic noise and the azimuth for the linear array. The information obtained indicated a very low level of microseismic noise. The records obtained in this survey were sent to Mr. Carl Romney, Chief Seismologist for the Contractor, for analysis at the Troy Office and he recommended that the array be constructed with an azimuth of N. 52° West and with an interstation separation of 2150 feet.

Preliminary discussions had been held between Mr. Ben R. Howard, Chief of Field Operations for the Contractor, and Colonel McConnell, the liaison officer at the Army post, concerning locations for the array suitable from a logistic standpoint. The Reservation is a very active training area and artillery practice is carried on daily in some parts of the area. Seismic noise is created by the recoil of guns, the passing of the shells through the air, and their explosion. An area in the extreme northwest part of the Reservation was selected for the location of the array, as this area is one of good granite outcrops. It is near Oklahoma Highway 49, which crosses the northwest corner of the Reservation and the nearest station site is a few hundred feet from a gate in the boundary fence. An REA electrical power line and a telephone line run along the highway. A sketch map (Figure C.1) shows the location of the stations. For convenience of reference and for security reasons this area is commonly referred to as <u>Area 11</u>.

The 46th Engineer Construction Battalion is stationed on the Reservation and arrangements were made with Lt. Col. W. P. Leber, Commanding Officer, for the Battalion to construct the instrument shelters at the four pier locations, with materials furnished by Beers and Heroy. Contract for the central recording building was let to W. A. Kite, Oklahoma City, Oklahoma. Work on the building commenced September 4 and was completed September 19. Electrical wiring was completed and power turned on September 27. The Engineer Battalion commenced work on September 6 and completed September 30. The shelters were very well constructed of durable materials and all piers are on firm bedrock. In addition, the Engineer Battalion cleared with a bulldozer a strip about 10 feet wide, removing brush and other vegetation for the location of the cables, as a precaution against grass fires. Installation of instruments was completed October 12 and test records were made 12 - 16 October when all instruments were working properly.

C.2.2 Description of Equipment at Fort Sill

The instrument vaults are buildings 10 feet by 10 feet by 6 feet 8 inches high with an entrance vestibule 3 feet 6 inches by

5 feet. The instrument piers extend to bedrock and are 4 feet by 4 feet and rise 6 inches above floor level. The floors are concrete; the walls are of concrete block 8 inches thick and the roof of wood-frame construction with mineral-surface roofing.

The central recording building is 17 feet 4 inches by 17 feet 4 inches, cement block construction, with frame roof. The building is divided into two dark rooms and one larger work room. One of the dark rooms has a concrete pier as a base for the recording instruments. The windows in the workroom were painted as a security measure.

The operating instruments at each pier consisted of one Benioff vertical seismometer; in addition, at Station A, were two Benioff horizontal seismometers, one installed N-S and one E-W. At the central recording station were three Benioff recorders. The following traces were recorded: (1) One conventional trace, horizontal N.S.; (2) one conventional trace, horizontal, E.W.; (3) one conventional vertical trace; (4) one earth-powered summation trace from four vertical seismometers; (5) one high-gain trace, horizontal N.S.; (6) one high-gain trace, horizontal E.W.; and (7) one high-gain vertical trace.

C.2.3 Installation of Station at Fort McClellan, Alabama

It was originally contemplated that, if local conditions proved suitable, this station would be installed at Dobbins Air Force Base, near Marietta, Georgia. Under the authority of Contract AF33(038)-17730, Supplement 2, examination of the area was made by Mr. Ben R. Howard on 23 and 24 August, who found that the base was approximately 3.75 miles NW-SE by 1.75 miles NE-SW. The base lies between a heavily-traveled four-lane highway, U.S. 41E, on the northeast and a two-lane highway, U.S. 41W, and the main line of the Nashville, Chattanooga and St. Louis Railroad on the southwest. The area is underlain by Pre-Cambrian biotite schist, which is generally quite deeply weathered, and several feet of excavation would be necessary to reach unweathered sound material. A noise survey in the area, 2 - 4 September, showed unsatisfactory noise conditions. It was decided, after conference with Mr. J. A. Crocker, to explore the possibilities of Fort McClellan, near Anniston, Alabama.

Scouting of that area began on 6 September. In the absence of Brigadier-General T. F. Wessels, Lt. Col. Scoggins made arrangements for access to the post and Major Leo Bertch, Post Engineer, provided military transportation.

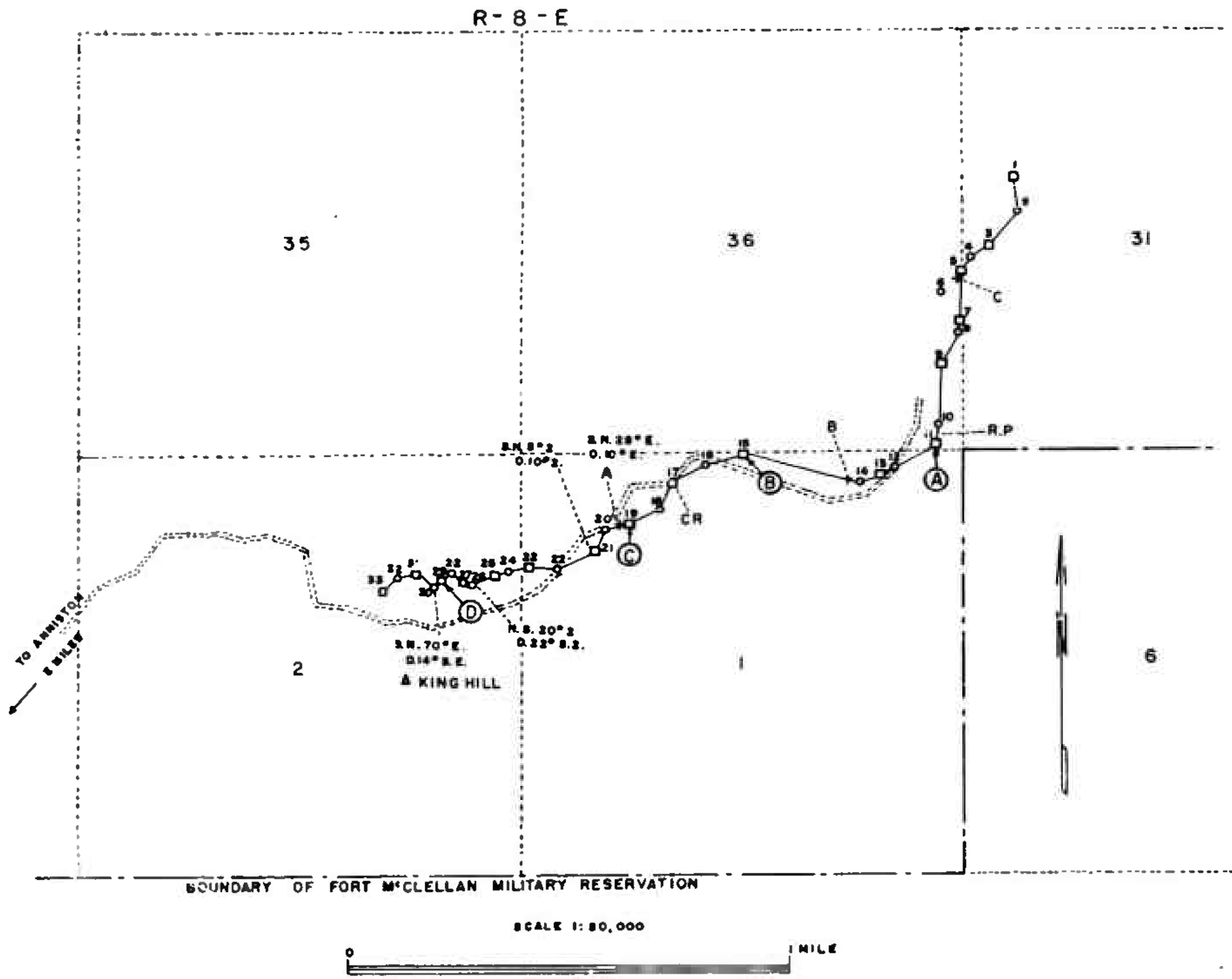


Fig. C.2 Sketch Map Showing Location of Seismic Station, Fort McClellan, Alabama

Fort McClellan Military Reservation is situated immediately northeast of the city of Anniston, Alabama. The post has recently been reactivated and is occupied by a detachment of troops of the Corps of Engineers, U.S. Army. The Reservation is approximately six miles E-W by seven miles N-S. The topography is hilly and rough, elevations ranging from 700 feet to 2000 feet. The southern part of the Reservation consists of hills and ridges underlain by Weisner (Cambrian) quartzite, a thick series of quartzitic sands, sandy shale, and hard quartzite. These sediments overlie metamorphosed Pre-Cambrian rocks. Overthrust faulting is present in the area. The area was considered geologically acceptable.

Commencing on 10 September, an array was laid out by Dr. W. B. Heroy, Jr., in the southeast part of the reservation and tests began on 18 September. Records were made and examined by Mr. C. F. Romney, who recommended an array with an E-W azimuth and a spacing of 2200 feet between stations. A sketch map (Figure C.2) shows the locations of the station, which is identified as <u>Area 12</u>.

Meanwhile, negotiations were in progress with local contractors for the construction of instrument shelters and Central Recording building. A contract was awarded to T. H. Pearce and Company on 20 September and the Contracting Officer's approval was received on 2 October. Construction in the field by Pearce and Company commenced on 11 October and piers were completed 12 October. Tents were erected and instruments installed to become operational 15 October. Buildings were not erected until the first part of November as work on them would have conflicted with recording.

C.2.4 Description of Equipment at Fort McClellan

The buildings erected at Fort McClellan are all of wood construction, the outside surfaces being chemically treated against weathering. Three of the instrument units (A, B and C) are 10 feet by 10 feet, with concrete floors and piers 4 feet by 4 feet, and have a vestibule; one (D) is 6 feet x 6 feet, without vestibule, and with a pier 2 feet by 2 feet. The central recording building is 16 feet by 16 feet and has no concrete pier. Cables were laid along the berm of the adjacent highway.

The setup of operating instruments and traces recorded was the same as that at Fort Sill.

C.2.5 Rehabilitation of Station near Encampment, Wyoming

The station near Encampment, Wyoming, identified as Area 5, was constructed under the authority of Contract AF33 (038)-17730 on the basis of site surveys made under Contract AF33 (038)-17625. The final report on Contract 17625 contains a map (p. 26) showing the general location of the station near Encampment.

Under the provisions of Contract 17730, change order of 9 June 1951, it was provided that the Encampment station should be operated on a standby basis, and this authorization was extended until 31 August 1951. Item 2 of the Statement of Work of Contract 5978 authorized the rehabilitation of the Encampment station "incorporating changes indicated as desirable by GREENHOUSE operations and changes necessary for year around operations". Authorization to proceed with work was received on 27 August 1951.

The work of rehabilitation of Area 5 consisted of the following principal tasks:

- (a) Construction on new locations of new and permanent instrument piers;
- (b) Erection of new instrument shelters on these piers;
- (c) Construction of service building with temporary living quarters;
- (d) Changing of location of cables;
- (e) Installation of new power generating equipment;
- (f) Improvement of access roads.

The spacing of the four instrument piers on the temporary locations was about 3700 feet with an azimuth slightly south of west. Locations for the permanent piers were made on a spacing of approximately 3000 feet and on an east-west azimuth. Piers are designated A, B, C, and D from east to west. The new location for Pier D was a few feet eastward from the original location. The new location for Pier C was about 550 feet southwest of the original location, which had proved unsatisfactory in operation because of excessive noise. Similar changes were made in the locations of Piers A and B.

The new piers were constructed on solid bedrock emplacements with dimensions of 4 feet by 4 feet. The instrument shelters over the piers were constructed with cement-block walls and concrete floor. Roofs were of wood construction with fire-resistant covering.

The service building is located about 300 feet north of the instrument shelter at Station C. It is of frame construction, with a concrete pier on which the engines of the power system are located. Its dimensions are 16 feet by 20 feet; 7 feet height to rafters. The

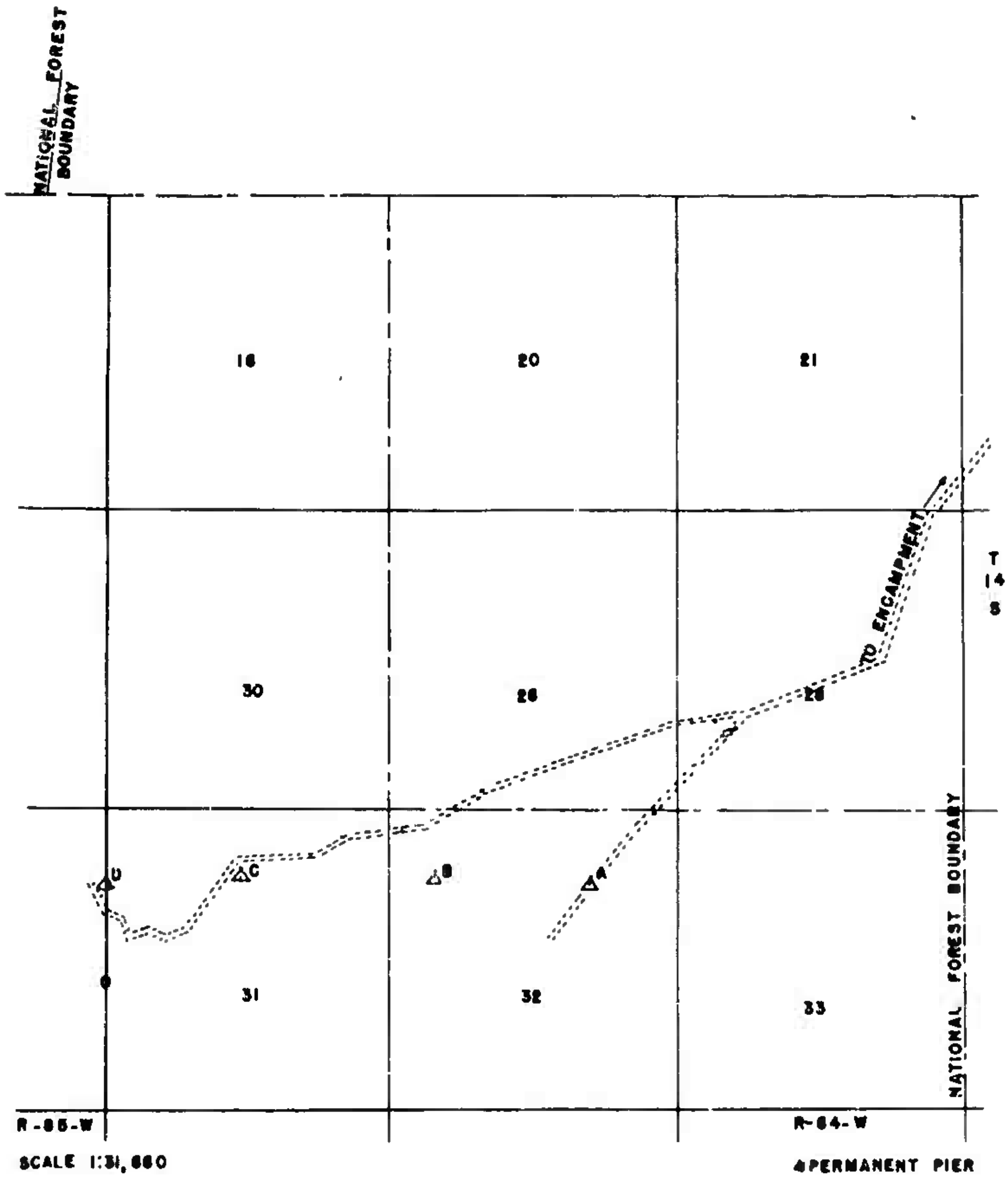


Fig. C.3 Sketch Map Showing Location of Seismic Station Near Encampment, Wyoming

power system consists of one 10-KW Witte diesel electric plant for normal service, and one 5-KW Kohler gasoline electric plant for relief service. The 5-KW generator automatically assumes the load upon interruption of service from the larger plant.

The road construction covered grading, installation of culverts, etc. on 4.8 miles of the road between Encampment and the station, the work being performed on the portion nearest the station and on the roads leading from the central station to the instrument shelters.

As it was not possible to let contracts for the building construction and road work until after 27 August the operations began much later than had been scheduled. The sub-contractors who had early in the summer made proposals for the work had their equipment and manpower tied up on other projects with the result that delays in starting and carrying on the rehabilitation of the station were inevitable. This made it necessary to carry on much of the construction after the first snowfall in the area.

The construction of the service building was commenced early in September and it was completed about 10 November. The diesel engine was placed in operation about 15 October. The gasoline generator was delivered 8 December. The construction of the instrument vaults was delayed because of difficulties in delivery of cement block and because the cold weather interfered with the pouring of concrete foundation. Construction began about 1 October and was not completed until 17 December.

The subcontractor on the road work commenced operations very promptly and completed the contract on 12 September.

Because of the delay in the completion of the instrument vaults the instruments were not moved to the new locations until early in December. By that time the cables were frozen to the ground and a great deal of labor was required in changing their location to connect with the new shelters. After the removal of the instruments and cable to the new locations, they were calibrated and the system placed in operation on 18 December.

The basic detection system at this station consisted of four Benioff vertical seismometers and two Benioff horizontal seismometers. One vertical instrument was installed in each of the instrument shelters described above so that the advantages of a linear array could be utilized. Station C, nearest to the central recording building, also housed the two horizontal instruments, one of which was oriented N-S and the other E-W. Three Benioff film recorders were installed along with two Esterline-Angus single channel ink recorders. The

components and combinations recorded on film at this station are listed: (1) Conventional trace, horizontal E-W; (2) conventional trace, horizontal N-S; (3) conventional trace, vertical A; (4) conventional trace, vertical B; (5) conventional trace, vertical C; (6) conventional trace, vertical D; (7) high-gain trace, horizontal E-W; (8) high-gain trace, horizontal N-S; (9) high-gain trace, vertical C. The high-gain traces recorded the output of the seismometer after amplification by a Perkin-Elmer break-circuit amplifier and filtering through a Beers-and-Heroy Type 1 band-pass filter which has a center frequency response at one cycle per second.

In addition to the film records described above, two summation traces were obtained on the ink recorders. Each of these traces recorded the summation of the signals from the four vertical seismometers after each had been separately amplified. For one trace this combined signal was filtered through a Beers-and-Heroy Type 2 band-pass filter with a center frequency at one cycle per second, and for the other trace the combined signal was filtered through a Krohn-Hite variable band-pass filter centered at about one-half cycle.

C.2.6 Rehabilitation of Station near Douglas, Wyoming

The station near Douglas, Wyoming, identified as Area 6, was located on the site surveyed under the provisions of Contract AF33 (038)-17625. The station was constructed under the authority of Contract AF33 (038)-17730. The final report on Contract 17625 contains a map (p.42) showing the general location of the station near Douglas.

Under the provisions of Contract 17730, Change Order of 9 July 1951, it was provided that the Douglas station should be operated on a standby basis, and this authorization was extended until 31 August 1951. Item 2 of the statement of work of Contract 5978 authorized the rehabilitation of the Douglas station "incorporating changes indicated as desirable by GREENHOUSE operation and changes necessary for year around operation". Authorization to proceed with work was received on 27 August 1951. The work of rehabilitation in Area 6 was essentially the same as that required in Area 5.

As a result of experience gained in the GREENHOUSE operation, it was concluded that a change in the spacing of the instrument locations and the azimuth of the array would be beneficial to reception. The instruments had been located originally on an azimuth of approximately S. 75° W. and an interval of 4400 feet. The azimuth was changed to S. 60° W. and the interval to 3000 feet in laying out the new array. The piers are designated as A, B, C, and D from east to west. This change of array required the shift of D about 2000 feet southeastward and similar changes in locations of the other instrument piers.

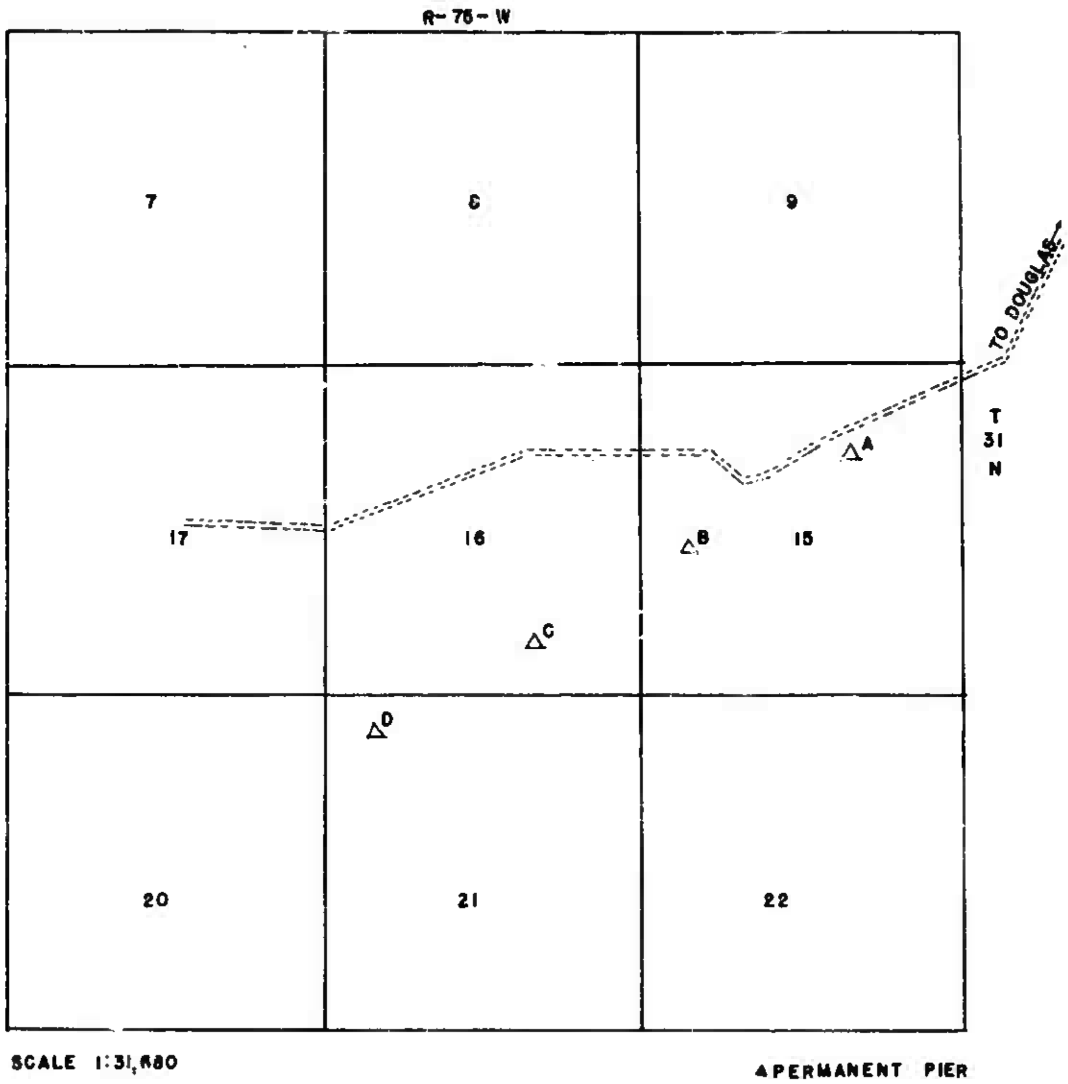


Fig. C.4 Sketch Map Showing Location of Seismic Station Near Douglas, Wyoming

The new pier locations were excavated to bedrock, a glaciated surface. The dimensions of the piers are 4 feet by 4 feet. The instrument shelters are of creosote-treated wood-frame construction, with concrete floors. Roofs are also of creosote-treated wood construction with fire-resistant coating. The service building is located about 1500 feet northeast of Station B. Its dimensions are 16 feet by 20 feet. The power system consists of one 10 KW Witte diesel electric plant for normal service and one 5 KW Kohler gasoline electric plant for relief service.

Road construction in Area 6 consisted of grading, draining, installing culverts, and surfacing with gravel approximately 0.8 mile of the access road westward from the central recording building to Pier D.

As authorization to commence work was not received until 27 August and approval of construction contracts was not received until the latter part of September, the commencement of work in the area was considerably delayed beyond the date originally planned. The construction of the service building was commenced about 25 August and it was completed early in November. The diesel engine was placed in operation about 15 October. The gasoline generator was delivered 6 December. The instrument shelters were essentially completed on 1 November. Cables were relaid and instruments moved to new locations during the first two weeks of November and the new array was first operated 15 November.

The instrument installation at this area is identical with that at Encampment except for the addition of a long-period vertical seismometer. This seismometer is known as Type DTMB and operates from a balanced capacity gap as one leg of a bridge system which is energized by a 100 kc carrier voltage. It is an instrument similar to the Reed E-D seismometer employed in Contract AF33 (038)-815. The DTMB seismometer has an adjustable period up to 20 seconds, but attainment of this period requires ideal ambient conditions of temperature and air motion. The record is obtained on a paper tape by the use of a Brush penmotor.

This long-period seismograph was operating during the last two events of the Nevada tests. The period was set at approximately 5 seconds and the magnification did not exceed 12,000. A greater magnification could not be used due to the relatively large microseisms present in the long-period spectrum.

C.2.7 Activation of Station near Carmel, New York

The station near Carmel, New York, is located about five

miles north-northwest of the city, which is the county seat of Putnam County, and about one mile east of the village of Farmers Mills. A map showing the location of the station is included in the Fifth Quarterly Progress Report on work performed under Contract AF33 (038)-815, dated 5 March 1950, Part 11, Plate 4.

The equipment reinstalled for this operation consisted of one Benioff vertical seismometer, one Benioff horizontal seismometer, and one Benioff film recorder. Two conventional earth-powered traces were recorded. The horizontal seismometer was oriented about north and south. No equipment was available for the operation of the station in addition to that just mentioned.

C.3.0 OPERATIONS

C.3.1 Operating Procedure

The procedures to be followed in conducting Operations JANGLE and BUSTER were established in Letter No. 55-4 dated 3 May 1951, issued by 1009th Special Weapons Squadron. It was originally contemplated that tests would commence on 1 October and continue through 30 November. By letter of 4 September, information was received that operations would be delayed 14 days and an operating program dated 10 October was sent by Beers and Heroy to stations under their supervision. Further postponements occurred and the first event actually occurred on 22 October.

C.3.2 Schedule of Events

All events originated within 10 km of a point in southern Nevada, Ground Zero being placed at Latitude 37°05' 31.5" N. and Longitude 116°01'25.6" W. As departures from the location of Ground Zero were along a NW-SE line, distances to Areas 4, 5 and 6 vary by much less than 10 km because of differences in the exact location of blasts. Chacteristics of the blasts are given in Table C.1.

C.3.3 Location of Stations

Instruments operated by Beers and Heroy were placed at rather large distances from the blasts, at locations intended to bracket a predicted shadow-zone for seismic body waves. The permanent sites at Areas 5 and 6 (distant 8.5° to 9.5°) fell within the edge of the shadow-zone on the near side, a new site at Area 11 was located to fall within the depth of the shadow (14°), while a new site at Area 12 and the station at HA_3 were to be beyond the shadow. Area 12 would actually be

TABLE C.1

Summary of BUSTER/JANGLE Blast Data

Blast	Date	Time (GCT)	Elevation Above Ground
Able	22 October 1951	14:30	100 feet
Baker	28 October 1951	15:20:08.8	1118 feet
Charlie	30 October 1951	15:00:30.6	1132 feet
Dog	1 November 1951	15:29:59.6	1417 feet
Easy	5 November 1951	16:29:58.2	1314 feet
Surface	19 November 1951	16:59:59.8	0
Underground	29 November 1951	19:59:59.7	Below surface but untamped

TABLE C.2

Location of Stations in BUSTER/JANGLE

Station Designator	Location	Distance from Origin**		Instruments
Area 4*	Laramie, Wyoming	9.3°	1028 km	B, Bv
Area 5	Encampment, Wyoming	8.2°	911 km	B, Bv, H, SS
Area 6	Douglas, Wyoming	9.6°	1069 km	B, Bv, H, SS
Area 11	Lawton, Oklahoma	14.4°	1600 km	B, H, SE
Area 12	Anniston, Alabama	24.8°	2760 km	B, H, SE
Station HA_3	Carmel, New York	32.7°	3640 km	Bv(1), Eh(1)

*Operated by military personnel

**Distances less than 10° were calculated by Richter's method, while greater distances were calculated by conventional formulae of spherical trigonometry.

B - Three-component Benioff installation

Bv - Three Benioff vertical seismometers

H - Three-component High-gain selective

SS - Summation, High-gain selective

SE - Summation, Earth-powered

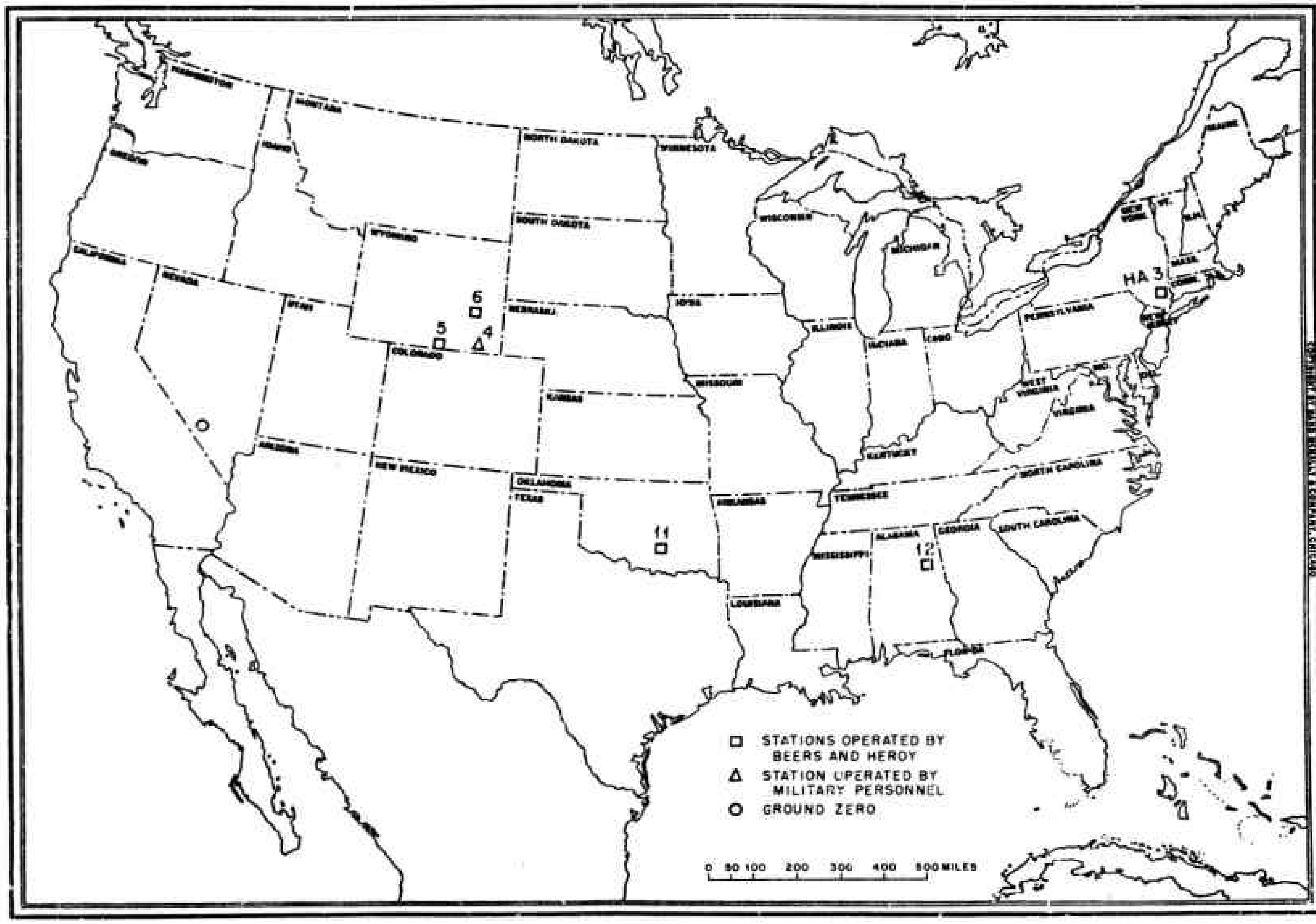


Fig. C.5 Map Showing Location of Long-Range Stations

near to a zone of abnormally high seismic amplitudes. The main characteristics of each location are listed in Table C.2 and the location of the stations is shown on the accompanying sketch map (Figure C.5).

C.4.0 EXPERIMENTAL RESULTS

In this preliminary report it is not to be expected that detailed analytical studies can be included. A selection of material follows that will furnish a fair measure of the success of the operation from the standpoint of long-distance recording. The resulting data are briefed and the principal inferences that have been drawn from these data are stated. In general, it is not anticipated that these preliminary conclusions will be appreciably altered by further studies. Questionable data and doubtful conclusions have generally been omitted.

C.4.1 Seismogram Readings

C.4.1.1 Shot Able

All seismograms negative.

C.4.1.2 Shot Baker

Possibly detected at Area 6 only. The seismograms from the high-gain summation instruments show fair correlation with summation records from Shots Charlie, Dog and Easy, particularly at about the expected time of $\overline{S}$. A comparison (Table C.3) of the amplitudes of $\overline{S}$, as recorded by the Area 6 summation seismograph, using the Krohn-H[illegible]e filter set to pass frequencies between 0.8 and 2.0 cycles per second, indicates that Shot Baker was about the same energy as Shot Charlie. If this is true, however, Area 5 should have recorded Baker. As it did not, and as the noise level at Area 5 remained practically constant over the time interval including Baker and Charlie, it seems probable that the summation seismograph at Area 6 was operating at considerably higher than the indicated gain and that, in reality, $\overline{S}$ from Shot Baker was considerably smaller than calculated. The Area 6 recording was strictly a borderline case and it is certain that the event would have been overlooked under all but the most careful examinations, even with the knowledge that the event had occurred.

TABLE C.3

A Comparison of the Amplitudes of $\bar{S}$,
as Recorded by the Area 6 Summation Seismograph

Shot	Stations in Summation	System Gain	Amplitude of $\bar{S}$	Signal to Noise
Baker	Vb, Vc	282,000	4.0 mm .014μ	2:1
Charlie	Vb, Vc	710,000	12.0 mm .017μ	6:1
Dog	Vb, Vc	610,000	16.0 mm .026μ	6:1

C.4.1.3 <u>Shots Charlie, Dog and Easy</u>

These three shots were detected at Areas 4, 5, and 6. Seismograms from Areas 11 and 12 and HA_3 were all negative.

Weather conditions on 1 November, in connection with the occurrence of Shot Dog 30 minutes earlier than scheduled, resulted in the loss of the initial phases at Area 6; S phases were successfully recorded, however. Seismograms from Area 4 did not show the Pn on any of the shots - a consequence of local noise conditions and of the very low amplitude of Pn at that distance (1028 km).

In making the analysis of the seismograms, independent measurements were first made on records of each shot, then records from the three shots were intercompared, and finally, features common to records of all blasts were selected for further study. For purposes of this report, particular emphasis is placed on the measurements of the characteristics of Shot Easy, which was the largest of the shots. Information on Charlie and Dog is in the form of measurements relative to those of Easy. Tables C.4, C.5 and C.6 give the basic information.

Pn - Normal first preliminary longitudinal wave observed at epicentral distances greater than about 150 km. Propagation path considered to be immediately below the crustal layers.

$\bar{P}$ - Normal first preliminary longitudinal wave observed at epicentral distances less than about 150 km. Propagation path considered to be in a superficial surface layer.

Pd - Observed late arrival longitudinal wave of this study. Propagation path not known.

Sn - Shear wave of same path as Pn.

$\overline{S}$ - Shear wave of same path as $\overline{P}$.

Sd - Shear wave of same path as Pd.

Travel-time information is presented in Figure C.6, and discussed in more detail in a following section of this report. Amplitude information is presented in Figure C.7.

TABLE C.4

Summary of Travel-Time and Amplitude Information for Shot Easy - Area 4

Phase	Component	Instrument	Travel-Time (min:sec)	Period (Sec)	Peak-Peak Amplitude μ
Pn	Not visible				
e	Z	Benioff	2:34	0.8	0.0052
iPd	Z	Benioff	2:54.7	1.0	0.0047
i$\overline{P}$	Z	Benioff	3:06.5	1.1	0.0073
	E	Benioff		1.0	0.0095
eSd	Z	Benioff	5:00		
e$\overline{S}$	Z	Benioff	5:20	1.1	0.0078
	E	Benioff	5:24	1.3	0.01
Noise	Z	Benioff		0.3	0.003
	Z	Benioff		0.05	0.001

TABLE C.5

Summary of Travel-Time and Amplitude
Information for Shot Easy - Area 5

Phase	Component	Instrument	Travel-Time (min:sec)	Period (Sec)	Peak-Peak Amplitude μ
iPn	Z	≤K-H;	2:02.2	1.2	0.00255
	Z	Benioff		0.4	0.00086
				0.5	0.00065
				1.2	0.0041
i(b)	Z	≤K-H;	2:05.1	1.0	0.0025
	Z	Benioff		1.0	0.0029
i(c)	Z	≤K-H;	2:11.4	1.0	0.0027
	Z	Benioff		1.0	0.0029
iPd	Z	≤K-H;	2:37.4	0.9	0.0038
	Z	Benioff		0.9	0.0055
i$\bar{P}$	Z	≤K-H;	2:44.3	0.9	0.0044
	Z	Benioff		0.9	0.007
iSd	Z	≤K-H;	4:31.2	0.9	0.004
	Z	Benioff		0.9	0.01
i$\bar{S}$	Z	≤K-H;	4:43.1	1.1	0.0086
	Z	Benioff		1.2	0.014
	NS	No record; Benioff recorder-motor stopped			

TABLE C.6

Summary of Travel-Time and Amplitude
Information for Shot Easy - Area 6

Phase	Component	Instrument	Travel-Time (min:sec)	Period (Sec)	Peak-Peak Amplitude μ
ePn	Z	Σ K-H;	2:23.4	0.7	0.0022
	Z	Benioff		0.4	0.0006
i	Z	Σ K-H;	2:35.8	1.0	0.0157
	Z	Benioff		1.0	0.004
iPd	Z	Σ K-H;	3:00.8	0.8	0.0113
	Z	Benioff		0.8	0.0027
e$\bar{P}$	Z	Σ K-H;	3:14.8	0.8	0.01
	Z	Benioff		0.8	0.0038
iSd	Z	Σ K-H;	5:11.2	0.9	0.026
	Z	Benioff		?	
i$\bar{S}$	Z	Σ K-H;	5:32.5	1.1	0.049
	Z	Benioff		1.8	0.055

C.4.1.4 Surface Shot

Possibly detected at Area 5 only. On the summation record (K-H filter), there is a general increase in activity at the predicted time, but definite phases are not in evidence. Signal-to-noise ratio is estimated at 1:1 or less.

C.4.1.5 Underground Shot

Possibly detected at Areas 5 and 6 only. Signal-to-noise ratio of 2:1 or less at Area 5; signal-to-noise ratio of 1:1 at Area 6. Definite phases were not discernible to the eye, but there exists a possibility that statistical correlation methods may be able to reveal phases on seismograms from Area 5.

C.4.1.6 Initial Earth Motion

First longitudinal motion appeared to be UPWARD on seismograms from Area 5 (Shot Easy) and Area 6 (Shot Charlie).

On other records the first motion is in doubt due to the unfavorable signal-to-noise ratios at the time of Pn.

C.4.2 Correlation Studies

As a step toward determining whether or not there are discriminatory characteristics of blasts, and if so, what these characteristics are, a number of correlation charts were computed. This method yielded considerable success with the GREENHOUSE seismograms, and it was hoped that similar success might result with recent seismograms. Specifically, it was hoped that the GREENHOUSE seismogram characteristic of a one-second pulse, followed after about 20 seconds by a short train of waves increasing in period to about 1.2 seconds, would be found to exist in the Pn group from the recent blasts. This hope was based on the similarity of GREENHOUSE records from locations at greatly different epicentral distances. Accordingly, cross correlations between records of the two blast series, from similar instruments were computed. Aside from a generally high (30%) "background correlation" on selective seismograms (to be expected, since noise characteristics are determined in large measure by the narrow pass-band of the instrument) no definite increase in correlation appeared at the expected time. The conclusion is, then, that the character associated with GREENHOUSE blasts was due either to local conditions at Eniwetok, or is to be found only in a blast signature when recorded at great distances.

Next, in order to find whether or not there were important similarities between Pn groups at Areas 5 and 6, correlation graphs were computed for Shot Easy. No correlation was found to exist, indicating little similarity between signatures at the two areas. Pn amplitudes were very low, however, and there is certainly an important effect of the background noise on this correlation.

The comparison of signatures at a single area from different blasts has not been completed; however, it is safe to say that a high correlation of the essential features will be found to exist. This statement is based on the fact that Pn, $\overline{P}$, Pd, $\overline{S}$ and Sd have been visually cross-correlated between records.

C.5.0 CONCLUSIONS

C.5.1 Travel Times

C.5.1.1 Pn-wave

Arrivals at Areas 5 and 6 are somewhat doubtful, due to the very low signal amplitudes, and hence the speed is not certainly known. The times as read are represented by

$$t = \frac{x}{7.45} \qquad (C.1)$$

where x is the epicentral distance in km and t is time in seconds. As this interpretation implies a surface layer of relatively high velocity, and as the usual $\bar{P}$ wave through the surface layer was detected, then it is apparent that the interpretation is not possible. If this is actually the same wave detected at smaller distances with a velocity of about 7.8 km/sec. (verbal communication from Mr. Crocker), then the observed waves are represented by

$$t = 5.4 + \frac{x}{7.8} \quad \text{(Area 5)} \qquad (C.2)$$

or

$$t = 6.3 + \frac{x}{7.8} \quad \text{(Area 6)} \qquad (C.3)$$

depending on which time is considered more reliable. An intercept of about six seconds implies propagation at a depth of the order of 15 km, which does not seem unreasonable.

C.5.1.2 Sn-wave

Not detected.

C.5.1.3 $\bar{P}$ wave

A strong arrival at Areas 4, 5, and 6 was detected exhibiting a velocity close to that usually associated with propagation in the upper (granitic) layer. Assuming the intercept at the origin to be zero, the times are best represented by

$$t = \frac{x}{5.52}\,. \qquad (C.4)$$

This wave was detected as the first arrival at distances less than about one degree (verbal communication) and apparently persists beyond nine degrees, although it is quite weak at Area 6 (9.6 degrees).

C.5.1.4 $\overline{S}$ wave

$\overline{S}$ was clearly detected at three sites (Areas 4, 5, 6), at a time represented by

$$t = \frac{x}{3.22} . \qquad (C.5)$$

Although relatively weak at Areas 4 and 5, the correspondence of the $\overline{P}$ and $\overline{S}$ waves on the seismograms is quite noticeable, and the agreement of the arrival times is excellent. At area 6, $\overline{S}$ is the outstanding wave on the records, with anomalously high amplitude compared to the same wave at other areas. The explanation for this is not known.

C.5.1.5 Pd wave

Identification of the propagation path of Pd has not been completed, and its significance is not known. Area 5 seismograms show it as a strong arrival just before $\overline{P}$; that it is a significant (non-random) arrival is verified by its existence on records of three events, and by the existence of the corresponding shear phase. An attempt to correlate Pd between stations was made, and, while amplitudes are somewhat low at Areas 4 and 6, the mutual agreement in time is good. Tentatively, the arrival time is considered to be

$$t = 22.4 + \frac{x}{6.75} . \qquad (C.6)$$

Such a large time intercept is difficult to explain, except as a result of a reflected or multiply-reflected propagation path.

C.5.1.6 Sd wave

Apparently of the same origin as Pd, this wave was observed at

$$t = 41.0 + \frac{x}{3.96} . \qquad (C.7)$$

Its significance is not known.

C.5.2 Amplitudes

Information on the amplitudes of the several waves at Areas 4, 5, and 6 is summarized in Figure C.7. In general, the waves

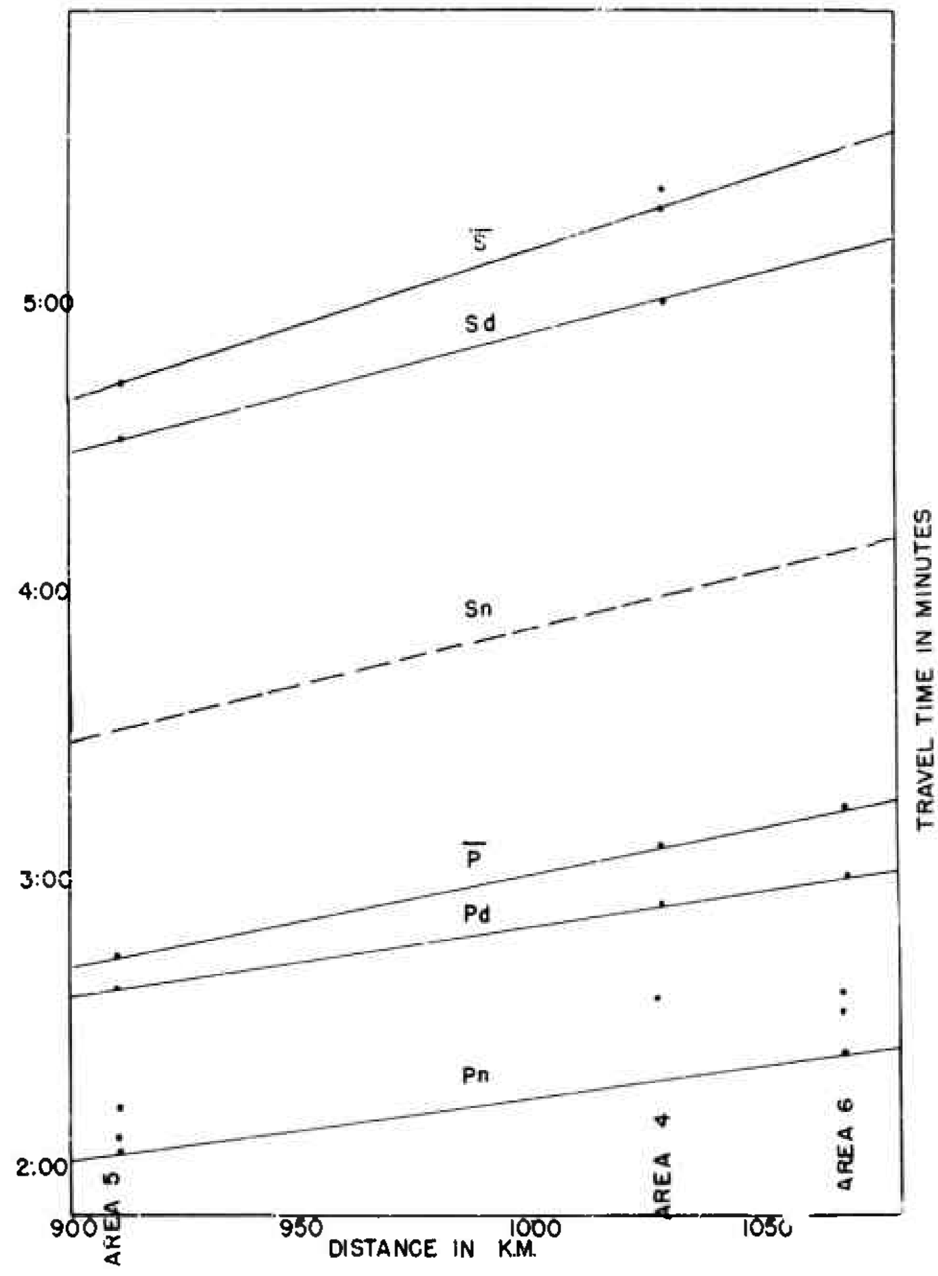


Fig.C.6 TRAVEL TIME CURVE BASED ON CHARLIE, DOG AND EASY SHOT

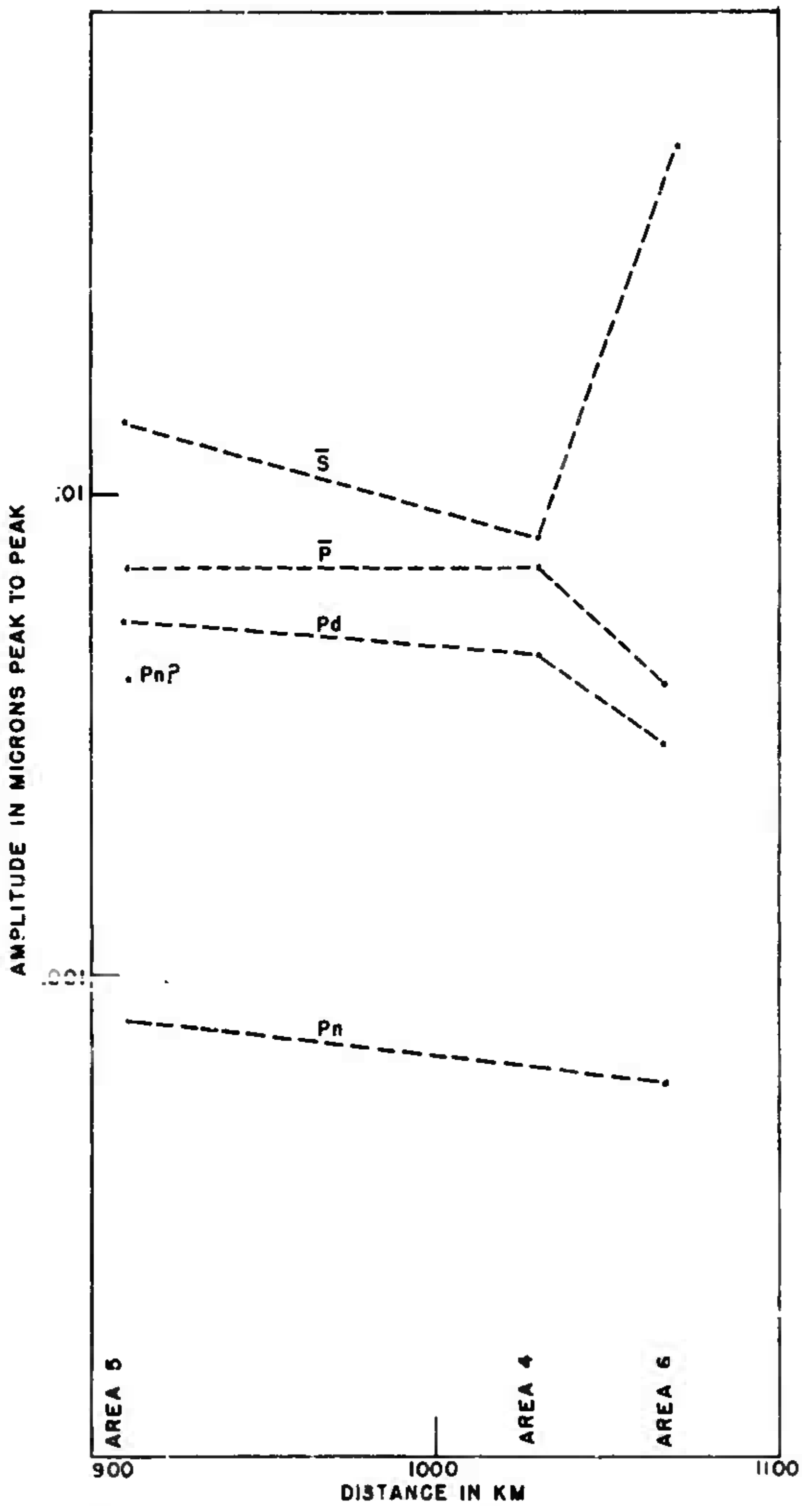


Fig. C.7 Attenuation Curve Based on Easy Shot

show a similar attenuation with distance, with the exception of the already mentioned anomalous amplitude of $\overline{S}$ at Area 6. The rate of attenuation is roughly of the order predicted by the earthquake magnitude studies of Gutenberg and Richter. Although it is difficult to make an exact estimate of the magnitude of Shot Easy, since the instrumental magnitude scale for small distances is given in terms of amplitudes measured on a standard Wood-Anderson horizontal seismograph and the blast recordings were for the most part registered on Benioff vertical seismographs, nevertheless, an estimate of about Magnitude 4.0 seems reasonable. In this case, amplitudes of the P waves at great distances, predicted by the magnitude for shallow focus events (although not surface events), would be of the order of 0.02 micron, peak-to-peak. This is clearly too large by perhaps one magnitude, since amplitudes of this size are routinely detected at USAF surveillance sites, and the blast in question was not detected at these sites.

The unusually large amplitude of $\overline{S}$ has, to the best of our knowledge, not been noted before in the case of large explosions; indeed, explosions not specifically designed to produce shearing forces are noteworthy for their lack of shear waves. As might be expected, the wave is predominantly SV and is most noticeable on the vertical components; horizontal shear components (SH) are hardly detectable. No reason can be given for the sudden increase in amplitude at Area 6.

0.5.3 Miscellaneous

The evaluation of the performance of the several types of instruments in the light of the general detection mission has not been completed. However, a few remarks may be made at present. In general, seismograms from the linear arrays at Areas 5 and 6 provided the most useful information on the blasts, and were most satisfactory for purposes of analysis. This was the result of the high magnifications obtainable and of the favorable aspect ratio (ratio of amplitude of seismic information to wave period) on these records. While most of the information to be found on the array seismograms was also present on the Benioff and high-gain selective seismograms, the very low ratio of amplitude to period on the film records made measurements difficult, and made it virtually impossible for an analyst to detect when a new significant phase appeared, or to differentiate between wave groups. The general feeling among the men who examined the records was that, for events of such small amplitude, the records would have been considerably improved in usefulness had they been able to cut the recording speed in half, and at the same time, double the gain.

On the other side of the picture, amplitude measurements on the array seismograms are subject to great uncertainty, since the recorded amplitude depends on ground amplitude, period, wave velocity and azimuth of arrival at the array. It may be noted from Tables 0.5 and 0.6 that the ratio of amplitudes on the array records to amplitudes on Benioff records decreases steadily with increasing time after the blast. This is a statement of the fact that later, slower arrivals (for a given frequency) fall more within the phase-cancellation band of the array than earlier faster arrivals. It was also noted that the random content of the recordings from the arrays at Areas 5 and 6 appeared to be higher than that noted on the Benioff. This may be the result of amplifier noise, or of variation of the parameters of the amplifiers.